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CORROSION PRODUCT TRANSPORT IN PWR SECONDARY SYSTEMS

- A LITERATURE REVIEW -

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ABSTRACT

The utilities' experience in corrosion product transport in pressurized water reactor (PWR) secondary systems is reviewed. During steady load operation, all studied plants had an iron concentration less than 15 ppb in the final feedwater which is well within the EPRI PWR Secondary Chemistry Guidelines recommended value of 20 ppb. However, the copper concentration in some of the feedtrains was above the recommended level of 2 ppb. Thus corrosion product transport may be used as a diagnostic tool to monitor the performance of cycle chemistry control.

Most of the corrosion products in transport are in particulate form. Iron and copper corrosion products in transport predominantly come from the condensate system except at plants with condensate polishers. Input from some side streams is also important.

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Although ammonia chemistry is capable of reducing system material corrosion to an acceptable level, recent tests appear to show that morpholine is a better pH control agent in reducing corrosion in 2 phase regions and corrosion product transport in the feedtrain.

Continuous blowdown is not an effective technique in removing corrosion products from the steam generators and sludge buildup is significant. To minimize corrosion product transport, preventative and controlling measures may be used.

Central Production Services Division is going to conduct corrosion product transport surveys in Ontario Hydro's nuclear power plants. Chemical Research Department, Research Division will be acting as a technical consultant. In addition, corrosion product sampling studies, to be carried out by Chemical Research Department, are suggested.

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EXECUTIVE SUMMARY

CORROSION PRODUCT TRANSPORT IN PWR SECONDARY SYSTEMS

- A LITERATURE REVIEW -

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Corrosion products are carried by feedwater into the steam generators and eventually deposit there to form sludge. Sludge deposits promote material corrosion underneath. This increases the risk of steam generator component failure. Developing strategies to control the buildup of deposits requires a detailed knowledge of the source, rate of transport and properties of the corrosion products. This information is normally obtained through sampling studies.

Corrosion products are composed of soluble and insoluble components. The insoluble component is further divided into filterables and non-filterables with respect to a 0.45 μm filter. During sampling, the filterables are captured by a 0.45 μm membrane filter while practically all of the solubles and non-filterables are retained on ion-exchange resin impregnated filters. All these together constitute the total corrosion products at that sampling location.

In a typical survey, a number of sampling points are selected and samples are taken. The samples are analyzed for the major elements present, e.g., iron, copper, etc. The 'element' concentration at different sampling locations is calculated using the sample volume recorded. The mass transport rate is then calculated with the 'element' concentration and the system flow rate. Corrosion product source, deposition and release rate, ingress rate to steam generators can be determined from the mass transport data.

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36-596-053	836.3332	May 4, 1990	90-105-K

22 corrosion product transport surveys were found in the literature search. All volatile treatment ammonia water chemistry is used in the power plants studied except where noted. Results of these surveys are summarized as follows:

1. Corrosion Product Concentrations

   During steady load operation, all studied plants had an iron concentration less than 15 ppb in the final feedwater which are well within the EPRI PWR secondary chemistry guidelines recommended value of 20 ppb. However, the copper concentration in some of the feedtrains was above the recommended level of 2 ppb. Thus corrosion product transport may be used as a diagnostic tool to monitor the performance of cycle chemistry control.

   During transients, corrosion product concentrations in the feedwater could be orders of magnitude higher than those during steady state full load operation. These transients would significantly increase the total corrosion product ingress to steam generators.

2. Corrosion Product Forms

   Most of the corrosion products in transport in the feedwater are present in filterable form except in the heater drains and moisture separator drains where the non-filterable form is also important.

3. Corrosion Product Transport

   Iron and copper in transport predominantly come from the condensate system except at plants with condensate polishers. Input from some side streams, e.g., HP heater drains and moisture separator drains, is also important. Corrosion product deposition and release can occur on heated surfaces along the feedtrain while deposition is observed in the deaerator.

4. Water Chemistry and Corrosion Product Transport

   Feedwater pH has a significant effect on corrosion product transport. Iron transport rate in mixed alloy feedtrains with pH operating at 8.8-9.2 is significantly higher than that in all ferrous feedtrains operating at pH around 9.6.

   Although all volatile treatment ammonia chemistry is capable of reducing system material corrosion to an acceptable level, recent tests, for example, at Prairie Island 2 and Point Lepreau, appear to show that morpholine is a better pH control additive in reducing corrosion in 2 phase regions and corrosion product transport in the feedtrain. Its effect on reducing sludge buildup in the steam generators is marginal and requires further investigation.

5. Sludge Buildup in Steam Generators

Continuous blowdown is not an effective technique in removing corrosion products from recirculating steam generators and sludge buildup is substantial.

Because of the minimal impact of blowdown on corrosion product removal from steam generators, controlling or minimizing total corrosion product transport are of significant interest. One approach is to prevent corrosion products from forming; another approach is to minimize their ingress to steam generators. If allowed to remain inside the steam generators, corrosion products will form sludge deposits. The deposits are normally removed by chemical cleaning or by mechanical means, e.g., water lancing.

(a) Preventative Measures

The following techniques may be used to prevent or minimize corrosion product formation in the secondary system and their accumulation in the steam generators.

(i) System Material and Feedwater pH

Mixed alloy feedtrains with pH operating at 8.8-9.2 will experience a higher corrosion rate than all ferrous feedtrains with operating pH at around 9.6. One alternative is to replace all copper alloy components by ferrous systems and raise the pH to a compatible level.

(ii) Air Ingress

Elevated dissolved oxygen concentration in the feedwater increases corrosion of system materials. Better maintenance procedures and system retrofits should be able to reduce oxygen ingress to a minimum.

(iii) Oxygen Scavengers

Hydrazine is commonly used to scavenge oxygen from the condensate and feedwater. The scavenging reaction goes faster at high temperature, dosage, and feedwater pH.

(b) Controlling Measures

Some known controlling techniques include the installation of condensate treatment systems and high temperature and pressure filters.

Ontario Hydro's steam generators already have a substantial amount of sludge accumulation. To assess the rates of corrosion product transport, Central Production Services Division (CPSD) is going to conduct transport surveys during steady state full load operation in all secondary systems. Chemical Research Department will be acting as a technical consultant to CPSD.

Studies (to be carried out by Chemical Research Department) are suggested to explore techniques in obtaining representative samples. The main areas of study include:

(1) Effect of sampling line length on sampling (this study should be carried out as soon as possible); and

(2) High temperature and pressure sampling.

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To: Dr. D. Mills
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CORROSION PRODUCT TRANSPORT IN PWR SECONDARY SYSTEMS

- A LITERATURE REVIEW -

1.0 INTRODUCTION

Corrosion products are formed in the secondary system as a result of corrosion of system materials. They are carried by feedwater into the steam generators but only a small fraction is removed by boiler blowdown. The corrosion products eventually deposit on heat transfer surfaces, on tube-sheets and in crevices. These deposits are porous and they provide sites for concentrating feedwater contaminants such as sodium, chloride, sulfate, etc. In time, the contaminants will reach a level that can cause material corrosion underneath. This increases the risk of steam generator component failure. Thus, controlling the buildup of deposits will assist in minimizing these failures.

Developing strategies to control the buildup of deposits requires a detailed knowledge of the source(s), rate of transport and properties of the corrosion products. This information may be obtained from corrosion product transport studies. Central Production Services Division (CPSD) is going to conduct such studies in Ontario Hydro's nuclear power plants. A preliminary survey has already been started at Bruce B, and systematic corrosion product transport studies will be starting, first at Bruce A, some time in the second half of 1990. Chemical Research Department will be acting as a technical consultant to CPSD. It is therefore advantageous to review the literature on corrosion product transport in PWR and CANDU secondary systems and to learn from the experience of other utilities. The review will also help CPSD and station personnel to better plan and carry out the surveys.

2.0 COMPOSITION OF CORROSION PRODUCTS

Corrosion products are composed of soluble and insoluble components (forms). The insoluble corrosion products are further divided into the filterables and non-filterables, and the relative amount of each depends on the pore size of the filter used. The generally accepted industrial standard in microfiltration of secondary system feedwater is 0.45 μm. Thus particles smaller than 0.45 μm are generally not collected by the filter membrane. If ion-exchange resin filters are used down stream of the membrane filter, the solubles and a major portion of the non-filterables will be retained by the resin filters (by adsorption). However, the analytical methods normally used do not distinguish the ratio of the soluble and the non-filterables. In this report, all corrosion products present on the resin filters are designated as non-filterables.

2.1 Factors Affecting Corrosion Product Forms

The following factors may affect the relative proportion of the filterables and non-filterables:

(a) Material of Construction of the Secondary System

Secondary system materials may be broadly divided into 2 types: ferrous and mixed alloy. The principal element in the corrosion products from an all-ferrous feedtrain is iron, while those from a mixed alloy feedtrain are iron and copper. Experience shows that iron is transported primarily as particulates while for copper the non-filterables are also important/1/.

(b) Plant Design Characteristics

Systems or components in the feedtrain that can remove or retain corrosion products will very likely change the relative proportions of the filterables and non-filterables. For example, besides having a lower concentration, samples collected after a full-flow condensate polisher or resin precoat filter will have a different proportion of non-filterables compared with those sampled upstream. Similarly, a deaerator facilitates particle sedimentation and samples collected downstream may have a higher ratio of smaller particles.

(c) Water Chemistry

For mixed alloy systems using ammonia to adjust feedwater pH, the copper alloy components in the presence of oxygen will react with ammonia to form a soluble ammonia copper complex.

$$Cu + 1/2\ O_2 + H_2O \text{ ----> } Cu^{2+} + 2OH^- \quad (1)$$

$$Cu^{2+} + 4NH_3 \text{ ----> } Cu(NH_3)_4{}^{2+} \quad (2)$$

These soluble corrosion products gradually decompose as the temperature increases to that of the steam generator. Thus, the insoluble (i.e., the filterable) fraction changes with sampling locations in the feedwater system.

3.0 SAMPLING METHODOLOGY

In general, two sampling techniques may be used: grab sampling and integrated sampling.

Grab sampling involves taking a predetermined volume of water at regular intervals and collecting the particulates by filtration. Because the concentration of corrosion products in feedwater is generally very low, a relatively large volume of water is required to give a few milligrams of particulates such that the detection limit of the interested elements is attained in chemical analysis. If the filterables are the main interest, grab sampling may be modified to filtering a predetermined volume of water through a filter attached to the sampling line. This procedure is then called integrated sampling. Grab sampling is very useful in situations when the system condition is changing rapidly, for example, during power transients. On the other hand, if the average particulate concentration during steady load operation is required, integrated sampling is preferred.

The schematic diagram of an integrated sampler designed by NWT Corporation/2/ is shown in Figure 3.1. The filtration station is designed to collect both the filterables and the non-filterables. A Millipore 0.45 μm membrane filter collects the filterable species from a sample flow of approximately 100 mL/min. Three cation exchange resin impregnated membranes can be inserted beneath the Millipore filter membrane to collect the soluble cationic species and colloidal species. Figure 3.2 shows a modified version, in which the non-filterables are collected by anion and cation resin columns. A sampling procedure using an integrated sampler similar to that in Figure 3.1 has been proposed by Stauffer/3/.

Some suggested sampling points in a typical PWR and CANDU secondary system/4,5/ are shown in Figures 3.3 and 3.4, respectively. To estimate corrosion product concentrations and transport rates in a secondary system, the following sampling points are normally used:

- condensate extraction pump discharge
- condensate polisher outlet (if present)
- low pressure heater outlet
- boiler feed pump discharge
- high pressure heater outlet
- boiler inlet
- boiler blowdown

- high pressure heater drains
- moisture separator drains
- reheater drains.

Samples are normally collected from lines routed to a central sampling room. It should be noted that a long sampling line from a process stream to sampling room may render the samples less representative because of particulate deposition and entrainment during transport/6/. A better method is to collect the corrosion products from local sampling points, i.e., as close to the process stream as possible.

4.0 CORROSION PRODUCT TRANSPORT IN SECONDARY SYSTEMS

Information on corrosion product transport is scattered. Literature search (restricted to articles in English only) was done in the Chemical Abstracts and Corrosion Abstracts and in Ontario Hydro's Report files. Surveys of the following plants are included in this review:

- Calvert Cliffs 1 /2/
- Ginna /2/
- Surry 2 /2/
- Trojan /2/
- Turkey Point 4 /2/
- St. Lucie 1 /7/
- Millstone 2 /8/
- Prairie Island 1 and 2 /2,9/
- Arkansas Nuclear One 1 and 2 /2,10/
- Crystal River 3 /2/
- Oconee 1 /2/
- Indian Point 2 /11/
- Fort Calhoun 1 /9/
- Beaver Valley 1 /9/
- Point Lepreau /12/

- Pickering 2 /13/
- Bruce 2 /14,15/
- A Japanese nuclear power plant (no name was given in the report) /16/
- Beznau /17/

All of these plants use recirculating steam generator system except Arkansas Nuclear One 1 (ANO-1), Crystal River 3 and Oconee 1, which use once-through steam generating system. The feedtrain metallurgy of these plants varies and the details are discussed in Appendix A. All volative treatment ammonia water chemistry is used in these plants except Fort Calhoun 1, Prairie Island 2, Beaver Valley 1, Pickering 2, Bruce 2 and Beznau 2, as noted in Appendix A.

Corrosion product transport surveys are performed for various reasons; for example,

- to establish a database and conformance of water chemistry specifications;
- to evaluate the performance of pH control additives;
- to study the effects of system retrofit(s), etc.

In a typical survey, a number of sampling points are selected and samples are taken (e.g., using the integrated sampler shown in Fig 3.1). The samples are analyzed for major elements present, such as iron, copper, nickel, zinc, etc. The 'element' concentration at different sampling locations is calculated using the sample volume recorded during sampling. The mass transport rate is then estimated with the element concentration and the system flow rate. An enormous amount of data is generated in a survey and these data are normally reduced and presented in graphical forms to facilitate data interpretation.

In the following section, results of the surveys are reviewed and discussed in general while the result summary of each utility survey is included in Appendix A.

4.1 Corrosion Product Concentrations

(a) During steady load operation

EPRI PWR Secondary Water Chemistry Guidelines/4/ recommend that the iron concentration in the final feedwater be less than 20 ppb during steady load operation, see Table 4.1. None of the studied plants had an iron concentration in the final feedwater higher than 14 ppb (see Tables 4.2 to 4.5). However, the copper concentration in some of the feedtrains was well above the recommended level of 2 ppb, e.g., at Indian Point 2/11/ and Bruce 2/14/. This means there may be some deficiencies in their cycle chemistry control. Indeed, in the Indian Point 2 survey, the dissolved oxygen levels in the condensate during the September, 1977 sampling study were at 50-55 ppb. In the Bruce 2 (1976) survey, even though the samples were taken after the system had reached steady load (approximately 90% full power) operation, the final feedwater copper concentration was 12 ppb. Such a high copper concentration might be caused by a high corrosion rate during the extended wet layup prior to startup. Thus, corrosion product transport surveys can be used as a diagnostic tool.

The highest corrosion product concentration occurs in the steam generator blowdown. The moisture separator drains usually have the second highest iron concentration but the mass transport rate is small compared with that of the feedwater because of lower flows.

For mixed alloy feedtrains, the iron concentration is generally higher than that of copper and the nickel concentration is generally lower than that of copper.

(b) During transients

Power level (hence system flow) changes cause a substantial increase in corrosion products in the feedwater. For example, during the startup at Bruce 2/14/ and Pickering 2/13/, distinct spikes in corrosion product levels could be observed corresponding to the ramp increases in reactor power (see Fig 4.1-4.3). The highest peak concentration was orders of magnitude higher than that obtained during steady state operation. It is suspected that changes in system flow slough off and stir up more corrosion products from the surfaces, producing these peak concentrations. These above "normal" concentrations may persist for a few days/13/.

4.2 Corrosion Product Forms

The percentage of filterable corrosion products varies with sampling locations. The results of some studied plants are summarized in Tables 4.6 and 4.7. In the condensate, at least 95% of the iron is in particulate form, except at Turkey Point 4 (89% filterable). For copper, over 80% is filterable except at Beaver Valley (73% filterable). The majority of the nickel is in filterable form with the percent filterable generally less than that of iron or copper.

At plants with condensate treatment, a significant portion of the corrosion products is removed by the demineralizer. The percent filterables in the demineralizer outlet is substantially lower than that at the inlet. This implies the average particle size is shifted to a smaller value.

In high pressure heater drains, the filterable fraction of iron and nickel vary extensively between plants and also with sampling periods at individual plants. The percent filterables of iron and nickel are generally lower than those in the condensate. For copper, at least 92% is in filterable form.

In the final feedwater, the percent filterables is generally lower than that in the condensate, partially reflecting the input with lower percent filterables from the high pressure heater drains. In steam generator blowdown, essentially all corrosion products are in filterable form.

The corrosion product form of zinc varies with sampling locations and from plant to plant, e.g., at Point Lepreau/12/, 28% to 81% is in filterable form; but at Pickering 2/13/, practically none is in filterable form.

4.3 Corrosion Product Transport

(a) Sources

Iron and copper in transport predominantly come from the condensate system (see Table 4.8 to 4.12). For plants with condensate treatment, the corrosion product level in the polished condensate is significantly reduced. Other important corrosion product sources include the high pressure heater drains and moisture separator drains.

For plants with copper alloy condensers, the origin of iron in the condensate appears to be intriguing. Actually, the condensate iron corrosion products are derived from corrosion of ferrous components of the condenser shell and baffling, shell side of low pressure heaters, low pressure steam piping and low pressure turbines, etc. These corrosion products are routed to the condenser hotwell.

Nickel in transport does not appear to originate mainly from the condenser, other sources such as HP heater drains and moisture separator drains are important as well (see Table 4.10). Nickel ingress to steam generators increases significantly if Monel is employed as the HP heater tube material (see Turkey Point 4 of ref. 2, and ref. 18).

(b) Corrosion Product Deposition and Release

Deposition or release may be deduced from corrosion product levels measured at the inlet and outlet of a system component. A higher concentration at the outlet implies a release of corrosion products; otherwise deposition occurs. For example, iron deposition was observed across the HP heaters/10,11/; the preheater/15/ and in the deaerator/12/; dropout of copper occurred along the feedtrain/7,10/. On the other hand, zinc/7/ and iron/12/ were estimated to be released from the LP heaters; nickel/2,14/ from Monel HP heaters.

Deposition and release estimates can be complicated by the solubility behaviour of the element at high temperature, especially when the particulate concentration is in the same order of magnitude as the solubility changes. As an illustration, the solubility of iron (in magnetite) decreases by approximately 6 ppb when the temperature increases from 150°C to 275°C at pH 9.7, see Figure 4.4. (These solubility curves were measured in the presence of hydrogen; they may not be directly applicable to secondary systems.) This means the iron corrosion product suspension will have a larger fraction of particulates at 275°C. If samples are collected at high temperatures and pressures, the results may be interpreted as a release of corrosion products. Thus deposition and release estimates should be verified with site inspection.

(c) Transport during Transients

Very limited information is available on corrosion product transport during various modes of operation. However, transients are known to increase significantly corrosion product transport to steam generators/13,14/. Point Lepreau/12/ conducted a study which included transports during startup and shutdown, see Table 4.12. During these 2 modes of operation, the overall iron transport rates to the steam generators appeared to be comparable, but the transport rates in the individual streams were quite different. Transport rate in the condensate during startup was almost 3 times lower than that during shutdown; transport rate in the HP heater drains was 5 times lower; but transport rate in the moisture separator drains was approximately 3 times higher; and in the boiler feed pump, it was about 30% higher. Such information could be very helpful in devising strategies to minimize corrosion product transport during transients.

4.4 Water Chemistry and Corrosion Product Transport

(a) Feedwater pH

Industry guidelines recommend that feedwater pH be maintained in the range 9.3-9.6 in ferrous feedtrains and 8.8-9.2 in secondary systems where carbon steel and copper alloys are both present/4/. Iron transport rates in systems with mixed alloy metallurgy are found to be significantly higher than those in all ferrous feedtrains/2/, see Table 4.9. This is because the feedwater pH used in mixing alloy feedtrains is a compromise, i.e., copper alloys have a minimum corrosion rate at pH 8-9/19/, see Figure 4.5, while carbon and low alloy steel will only have an acceptable corrosion rate at pH 9.3-9.6/20/, see Figure 4.6.

Based on corrosion product transport, an optimum pH could be established for a particular secondary system. For example, a Japanese power plant/16/ determined an optimum feedwater pH to be 9.2 by monitoring the iron, copper and nickel transport in the feedwater and the moisture separator drains at various pH values. In those tests, iron and nickel concentration in the feedwater decreased as the feedwater conductivity (hence pH) increased. However, copper concentration in the feedwater started to increase above a conductivity value of 4.5 μS/cm (25^{o}C), which corresponds to a pH value of 9.2 approximately. It must be pointed out that feedwater optimum pH is rather plant specific since it relates to system design, feedtrain metallurgy and cycle chemistry.

(b) pH Control Additive

At most plants, ammonia and/or hydrazine are added to increase feedwater and condensate pH to reduce corrosion rates to acceptable levels. A significant portion of the corrosion products in the feedwater results from erosion-corrosion of two phase regions of a secondary system, e.g., condenser internals, steam extraction piping, heater shells and drain piping. This phenomenon may be attributed to the relatively high steam-to-liquid distribution coefficient of ammonia. Corroding surfaces in two phase regions are covered with liquid films, the pH of the liquid films dictates the corrosion rate of the surface metal. With ammonia, because of the relatively high steam-to-liquid distribution coefficient, less pH control additive (hence a lower pH) is present in the liquid phase. This results in higher surface corrosion rates. pH control additives with lower steam-to-liquid coefficient can provide some remedy. Morpholine has been tested at several stations/9,12/, e.g., Point Lepreau/12/, Prairie Island 2 and Beaver Valley 1/9/, and appears to be a promising candidate.

Point Lepreau NGS conducted a corrosion product transport study in some 2 phase regions, when switching from ammonia to morpholine chemistry/12/. The total iron concentrations at the high pressure heater outlet and reheater drains were somewhat affected by the water chemistry changes. However, in the moisture separator drains and high pressure heater drains, significant reduction in total iron concentrations and transport rates were observed (See Table 4.13). With the feedwater pH at 9.2, the total iron concentration in the moisture separator drains and HP heater drains reduced from 28.4 ppb and 26.7 ppb to 9.4 ppb and 9.9 ppb, respectively. The total iron transport rate in these 2 streams reduced from 9.2 g/hr and 19.5 g/hr to 3.0 g/hr and 7.2 g/hr, respectively. At pH 9.5, the trend was similar but the changes were somewhat smaller. Of the 2 components in the iron corrosion products the biggest reduction occurred in the non-filterable iron when ammonia was replaced by morpholine. Based on these results morpholine appears to mitigate the erosion-corrosion in 2-phase regions at Point Lepreau.

Prairie Island 2 has an all ferrous feedtrain/9/. Morpholine was introduced on June 11, 1986 after collecting approximately three weeks of baseline data with ammonia/hydrazine operation. The feedwater morpholine concentration was maintained at approximately 4 ppm during the study (see Figure 4.7). The ammonia present in the feedwater was estimated to be approximately 2 ppm. Tables 4.14 and 4.15 compare the average corrosion product concentrations and transport rates during ammonia and morpholine operations. Iron concentrations and transport rates at all cycle locations decreased significantly with the transition to morpholine chemistry. Morpholine chemistry also appears to have significantly reduced the iron removal rate from the steam generators by blowdown (see Figure 4.8). As a result, the sludge buildup rate in the steam generators was marginally reduced with the transition. However, during ammonia operation elevated blowdown iron concentrations were observed for approximately 2 weeks subsequent to the May 20, 1986 shutdown. This led to an elevated value for blowdown removal efficiency. The authors therefore believed that under normal steady load operation, a higher reduction in iron buildup rates should be achieved.

At Beaver Valley 1, morpholine is used since initial startup in 1976/9/. The corrosion product concentrations and transport rates are comparable to those of other power plants included in this review (see Tables 4.5 and 4.11), but the blowdown removal rate at Beaver Valley 1 is significantly lower. Interestingly, no significant sludge buildup has been observed in the steam generators at Beaver Valley 1/21/. This appears to be contrary to the experience of other utilities that use morpholine chemistry, e.g. Pickering NGS has found significant sludge buildup in the steam generators.

These data appear to show that morpholine has some promising capabilities of reducing corrosion in 2 phase regions and corrosion product transport in the PWR secondary cycle at the same feedwater pH established for ammonia. However, its effect on reducing sludge buildup in steam generators appears to be marginal and requires further investigation. Also, morpholine decomposition leads to increased concentrations of formate, acetate, and other organics throughout the cycle/20/, the deleterious effects of these species are not known.

Other pH control additives tested include aminomethylpropanol (AMP) and cyclohexylamine (CHA). AMP combined with dimethylaminopropanol (DMAP) has been used at Fort Calhoun/9/. No significant effect on corrosion product transport was observed probably due to the low concentration of AMP-DMAP used (0.4 ppm). Cyclohexylamine (CHA) was tried at Beznau 2/17/. Within the concentration range used (0.13 ppm to 3.6 ppm), CHA appeared to reduce the iron transport in the feedwater and moisture separator drains.

4.5 Sludge Buildup in Steam Generators

Continuous blowdown is employed to control the concentration of ionic species and to remove particulates from recirculating steam generators. Its efficiency for removing corrosion products is rather poor (see Tables 4.8 to 4.12) and sludge buildup in steam generators is substantial. The actual amount, however, should be confirmed by inspection.

5.0 CONTROL OF CORROSION PRODUCT TRANSPORT IN SECONDARY SYSTEMS

Because of the minimal impact of blowdown on corrosion product removal from the steam generators, controlling or minimizing total corrosion product transport is of significant interest. One approach is to prevent corrosion products from forming; another approach is to minimize their ingress to the steam generators. If allowed to remain inside the steam generators, corrosion products will form sludge deposits. The deposits are normally removed by chemical cleaning or by mechanical means, e.g., water lancing.

5.1 Preventative Measures

Corrosion products are prevented from forming or reduced to a minimum by using one or a combination of the following techniques.

5.1.1 System Materials and Feedwater pH

The corrosion rate of carbon and low alloy steel is only reduced to an acceptable level by maintaining the pH at around 9.6/19/. Mixed alloy secondary systems which maintain the feedwater pH at 8.8-9.2 will experience a higher corrosion rate/2/. One option is to replace all copper alloy components by ferrous systems and raise the pH to a compatible level. This was done, for example, at St. Lucie 1, where the condensers were retubed with titanium and the heaters with stainless steel/7/; and at Millstone 2, where the LP heaters were retubed with stainless steel/8/. However, system retrofits are expensive.

Most power plants use ammonia as a pH control additive. Recently, morpholine has been tested as a substitute for ammonia and appears to be effective in reducing corrosion in 2 phase regions and corrosion product transport in the feedtrain/9,12,21/. It is suggested that Ontario Hydro should evaluate the benefits of morpholine chemistry at stations that currently use ammonia chemistry.

5.1.2 Air Ingress

Air ingress elevates the feedwater dissolved oxygen and increases corrosion of system materials. Major locations for oxygen ingress include turbine-condenser expansion joint, valves, condensate storage tank, and makeup system. Better maintenance procedures, monitoring procedures, and system retrofits should be able to reduce oxygen ingress to a minimum/21/. A more detailed account that describes techniques in reducing air ingress into the secondary system is discussed in Ref. 23, 24, 25. Ontario Hydro has devised an air ingress control program to minimize and control air leakage in its secondary systems/26/.

5.1.3 Oxygen Scavengers

Hydrazine is used by most plants to scavenge oxygen from the condensate and feedwater. The oxygen scavenging reaction of hydrazine depends on 3 factors: reaction temperature, dosage, and feedwater pH.

a) Reaction Temperature

Hydrazine is more effective at high temperatures, e.g., like that experienced in the high pressure feedwater heaters/27/ (see Fig. 5.1). Unfortunately, at high temperatures the reactivity of oxygen with the feedwater heater and piping materials is also high. To avoid this problem, most of the oxygen removal afforded by hydrazine should take place in the low-pressure feedwater heaters. This was demonstrated in a study at Indian Point-2/11/.

Hydrazine was shown to substantially reduce oxygen concentrations in the low pressure feedwater heaters, but it made little difference in oxygen concentrations in the high-pressure feedwater heaters and steam generator inlet. Also, the deaerator in a feedtrain improves oxygen removal by providing a longer residence time.

b) Dosage

The effectiveness of hydrazine increases significantly with dosage. Fig. 5.1 illustrates the reaction time of hydrazine with oxygen at 2 different doses and temperatures/27/. These results indicate that an overdose of hydrazine is required to maximize oxygen removal e.g., 3 times the oxygen concentration in the feedwater (as recommended by the EPRI water chemistry guidelines/4/). The maximum hydrazine dosage that can be tolerated is determined by the amount of ammonia carryover from hydrazine decomposition and system metallurgy.

c) Feedwater pH

The scavenging capability of hydrazine increases with pH/27/. Thus, the condensate/feedwater pH should be maintained at the highest level consistent with the system metallurgy to further enhance oxygen removal.

A recent study by van Berlo and Dundar/28/ showed that a feedtrain with deaerator, e.g., Gentilly-2, may not need hydrazine as an oxygen scavenger. Gentilly-2 has been operating without hydrazine since March 1984, and morpholine is the pH control additive used. Dissolved oxygen levels in the feedtrain of Gentilly-2 were similar to those of Point Lepreau, even though Point Lepreau used 100-200 ppb hydrazine (see Fig 5.2). The iron transport levels in both feedtrains were comparable. However, the blowdown corrosion product concentration was lower at Gentilly-2 (see Table 5.1), which appears to be characteristic of morpholine water chemistry (see Reference 9).

5.2 Controlling Measures

5.2.1 Condensate Treatment

Condensate demineralizers are capable of reducing ionic impurities and retaining corrosion products in the feedwater. The use of condensate treatment can, therefore, lead to reduction in corrosion product ingress to steam generators, see Table 5.2. The reduction is rather plant specific and may depend on parameters, such as feedwater pH, configuration of the drain routing system, etc. None of Ontario Hydro's nuclear power plants has condensate polishers and Ontario Hydro will not likely retrotfit the secondary systems with condensate polishers given the cost and problems associated with the operations/29/.

5.2.2 High Temperature and Pressure Filtration

Most of the corrosion products carried into the steam generators are in particulate form. Removing these particulates from the feedwater by filtration is most effective in preventing their buildup in the steam generators. Ideally, the filtration should be done close to the inlet of the steam generators, i.e., after the last high pressure feedwater heater. However, if filtration of the full flow is impractical, that of a stream carrying the major quantity of corrosion products should be considered. Electromagnetic filters have been demonstrated to be suitable for filtration of high temperature water/30/. Darlington Engineering (of Ontario Hydro) has a prototype electromagnetic filter designed and manufactured by Babcock and Wilcox Canada Ltd. The unit is available for further studies/31/ and there are no immediate plans for testing the equipment in Ontario Hydro's secondary systems.

6.0 CORROSION PRODUCT TRANSPORT STUDIES

6.1 Sampling Studies

In the surveys reviewed, the samples are believed to be collected from sampling lines in a central sampling room relatively far from the process streams. These sampling lines may be several hundred feet long. During sample transport, deposition or entrainment may occur. In addition, sample conditioning, i.e. reducing the sample condition to ambient temperature and pressure, may change the relative concentration of the filterables and non-filterables. All these factors render the sample non-representative. It is suggested that Chemical Research Department should investigate the following:

a) Effect of Sampling Line Lengths

Samples are to be collected simultaneously from local sampling points and from the corresponding sampling lines in the central sampling room. The effects of sampling line length can therefore be compared. A detailed description of the project has been submitted to CPSD for funding consideration/32/.

b) Effect of Sample Conditioning

A high temperature and pressure sampling panel for water borne particulates is being bought from Sentry Equipment Corporation (Wisconsin, U.S.A.). Samples collected at system conditions will be compared with those collected at ambient conditions at local sampling points.

6.2 Survey of Ontario Hydro's Nuclear Power Plants

Sludge deposits are known to promote under deposit corrosion. Recently, corrosion product fouling of the steam generator upper tube support plates has caused derating of units 1 and 2 at Bruce A. Therefore, controlling corrosion product ingress and preventing sludge buildup are essential to maintain steam generator integrity and power production. To assess the rates of corrosion product transport, CPSD is going to carry out transport surveys in all secondary systems of Ontario Hydro's nuclear power plants. The first phase of the program will cover steady state full power operations. The program may be extended to cover startup and shutdown of some typical secondary systems. This will establish a data base for Ontario Hydro's secondary systems. Chemical Research Department will be acting as a technical consultant to CPSD. The information gained in reviewing the literature will be directly applicable to the program.

It is suggested that after a corrosion product transport data base has been established CPSD should also optimize the water chemistry of the secondary systems. A preliminary study has already been started at Bruce B unit 7 in which morpholine is added to the feedwater to a predetermined level to replace ammonia as the pH control additive. However, a more systematic approach is preferred in which a typical all-ferrous system and a typical mixed alloy system will first be selected and their cycle chemistry optimized using corrosion product transport rates as the main criterion. The water chemistry parameters will include feedwater pH, hydrazine concentration, and pH control additive level. The established conditions will serve as a guide to CPSD to devise plans to optimize the water chemistry of the other secondary systems. It should be mentioned that the lowest achievable corrosion product concentration in the feedwater is rather plant specific and is affected by subtle changes in plant design, materials of construction, conditions of individual components, etc.

7.0 CONCLUSION AND RECOMMENDATIONS

7.1 The utilities' experience in corrosion product transport in PWR secondary systems has been reviewed. During steady load operation all studied plants had an iron concentration less than 15 ppb in the final feedwater which is well within the EPRI PWR Secondary Chemistry Guidelines recommended value of 20 ppb. However, the copper concentration in some of the feedtrains was above the recommended level of 2 ppb. Thus corrosion product transport may be used as a diagnostic tool to monitor the performance of cycle chemistry control.

Corrosion product concentrations in the feedwater during power transients could be orders of magnitude higher than those during steady state full load operation. Power transients would increase significantly the total corrosion product ingress to steam generators.

The majority of the iron in transport in the feedwater is present in filterable form. In the heater drains and moisture separator drains, the non-filterable form is also important. Copper in transport is generally in filterable form. The majority of the nickel in transport is also in filterable form with the percent filterable generally less than that for iron or copper.

Iron and copper in transport predominantly come from the condensate system except at plants with condensate polishers. Input from some side streams, e.g. HP heater drains and moisture separator drains, is also important. Corrosion product deposition and release can occur on heated surfaces along the feedtrain and deposition usually occurs in deaerators.

Feedwater pH has a significant effect on corrosion product transport. Iron transport rate in mixed alloy feedtrains with pH operating at 8.8-9.2 is significantly higher than that in all ferrous feedtrains operating at pH around 9.6. Although all volatile treatment ammonia chemistry is capable of reducing system material corrosion to an acceptable level, recent tests appear to show that morpholine is a better pH control additive in reducing corrosion in 2 phase regions and corrosion product transport in the feedtrain.

Continuous blowdown is not an effective technique in removing corrosion products from recirculating steam generators and sludge buildup is significant. To minimize secondary system corrosion product transport, preventative and controlling measures may be used. The important preventative techniques are: choice of feedwater pH and system materials, controlling air ingress, and addition of oxygen scavengers; and some controlling measures include installation of condensate treatment system and high temperature and pressure filtration system.

7.2 Ontario Hydro's steam generators already have a substantial amount of sludge accumulation. To assess the rates of corrosion product transport, CPSD is going to conduct transport surveys during steady state full load operation in all secondary systems. Chemical Research Department will be acting as a technical consultant to CPSD.

It is suggested that after a corrosion product transport data base has been established CPSD should also optimize the water chemistry of the secondary systems. This may be accomplished by first selecting a typical all-ferrous feedtrain and a typical mixed alloy feedtrain and optimizing the water chemistry of these 2 feedtrains using corrosion product transport rate as the main criterion. At the completion of the program, plans are to be devised to apply the established optimum water chemistry conditions to other secondary systems.

7.3 Studies (to be conducted by Chemical Research Department) are also suggested to explore techniques in obtaining representative samples in corrosion product transport surveys. The main areas of study include:

(a) Effect of sampling line length on sampling (this study should be carried out as soon as possible); and

(b) High temperature and pressure sampling.

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TABLE 4.1

FEEDWATER CHEMISTRY PARAMETERS FOR SECONDARY SYSTEM WITH RECIRCULATING STEAM GENERATORS

Parameter	Frequency	Normal Value	Action Level		
			1	2	3
pH (ferrous system)	continuous	9.3-9.6	<9.3 >9.6		
pH (ferrous/copper system)	continuous	8.8-9.2	<8.8 >9.2*		
Cation Conductivity, µmho/cm	continuous	<0.2	>0.2		
Sodium, ppb	continuous	<3	>3		
Dissolved O_2, ppb	continuous	<3	>3		
Total Iron, ppb	weekly (integrated)	<20	>20		
Total Copper, ppb	weekly (integrated)	<2	>2		
Hydrazine, ppb	daily	$>3 \times [O_2]$**	$<3 \times [O_2]$**		
pH Control Additive	daily	***	***		

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* Action required only if experience shows increased copper transport at pH > 9.2

** Based on oxygen value measured in the condensate sample

*** To be consistent with pH

TABLE 4.2

COMPARISON OF STEADY STATE IRON CONCENTRATIONS (ppb)
AT SOME US PWRs

	Condensate Polishing[a]	Condenser Material[b]	Feedwater Heater Material[b]	Reheater Material	Condensate	Polished Condensate	High Pressure Drains	Moisture Separator Drains	Feedwater	Blowdown
Recirculating Steam Generator Systems										
Calvert Cliffs 1	None	70/30 CuNi	SS	90/10 CuNi	10.8	NA[c]	—	—	12	370
	PRF	70/30 CuNi	SS	90/10 CuNi	11.1	—	—	—	9.6	350
Ginna	DB	Admiralty	Copper Alloy	90/10 CuNi	15.0	2.2	—	—	—	—
Prairie Island 1	None	SS	SS	CS	10	NA	17	—	11	320
	PRF				5.2	0.2	—	—	—	—
Prairie Island 2	None	SS	SS	CS	11	NA	6.8	23	13	1340
	PRF				5.5	0.3	—	—	—	—
Surry 2	None	90/10 CuNi	Copper Alloy	90/10 CuNi	10.9	NA	10.5	—	11	250
Trojan	PRF	Admiralty	Copper Alloy	90/10 CuNi	10.5	0.1	13	—	4	—
Turkey Point 4	None	Alum. Brass	Copper Alloy	90/10 CuNi	13.4	NA	—	—	14	930
St. Lucie 1	None	Titanium	Admiralty SS	90/10 CuNi	7.4	NA	14	—	8.5	—
Millstone 2	DB	70/30 CuNi	Copper Alloy SS	90/10 CuNi	8.8	1.5	—	—	—	40
Once-through Steam Generator Systems										
ANO-1	DB	Admiralty	SS	90/10 CuNi	12.3	2.1	20	65	8.2	NA
Crystal River 3	DB	70/30 CuNi	SS	90/10 CuNi	13.3	3.7	5.7	—	10	NA
Oconee 1	PRF	SS	SS, CS	CS	5.3	0.4	8.0	37	4.5	NA

a) PRF = Powdered Resin Precoat Filters
DB = Deep Beds

b) SS = Stainless Steel
CS = Carbon Steel

c) NA = Not Applicable

Note: St. Lucie 1, see ref. 7
Millstone 2, see ref. 8
Other power plants, see ref. 2

TABLE 4.3.

COMPARISON OF STEADY STATE COPPER CONCENTRATIONS (ppb) AT SOME US PWRs

	Condensate Polishing[a]	Condenser Material[b]	Feedwater Heater Material[b]	Reheater Material	Condensate	Polished Condensate	High Pressure Drains	Moisture Separator Drains	Feedwater	Blowdown
Recirculating Steam Generator Systems										
Calvert Cliffs 1	None	70/30 CuNi	SS	90/10 CuNi	0.7	NA[c]	--	--	0.4	20
	PRF	70/30 CuNi	SS	90/10 CuNi	0.6	--	--	--	0.5	20
Ginna	DB	Admiralty	Copper Alloy	90/10 CuNi	0.8	0.08	--	--	--	--
Prairie Island 1	None PRF	SS	SS	CS	NA	NA	NA	NA	NA	NA
Prairie Island 2	None PRF	SS	SS	CS	NA	NA	NA	NA	NA	NA
Surry 2	None	90/10 CuNi	Copper Alloy	90/10 CuNi	1.6	NA	1.7	--	1.6	14
Trojan	PRF	Admiralty	Copper Alloy	90/10 CuNi	2.4	0.3	0.8	--	0.4	--
Turkey Point 4	None	Alum. Brass	Copper Alloy	90/10 CuNi	2.1	NA	--	--	1.4	28
St. Lucie 1	None	Titanium	Admiralty SS	90/10 CuNi	0.17	NA	0.23	--	0.13	--
Millstone 2	DB	70/30 CuNi	Copper Alloy SS	90/10 CuNi	1.1	0.2	--	--	--	5.3
Once-through Steam Generator Systems										
ANO-1	DB	Admiralty	SS	90/10 CuNi	2.9	0.3	0.3	0.7	0.3	NA
Crystal River 3	DB	70/30 CuNi	SS	90/10 CuNi	1.2	0.3	0.4	--	0.1	NA
Oconee 1	PRF	SS	SS, CS	CS	<0.15	<0.1	0.1	0.5	<0.1	NA

a) PRF = Powdered Resin Precoat Filters
DB = Deep Beds

b) SS = Stainless Steel
CS = Carbon Steel

c) NA = Not Applicable

Note: St. Lucie 1, see ref. 7
Millstone 2, see ref. 8
Other power plants, see ref. 2

TABLE 4.4

COMPARISON OF STEADY STATE NICKEL CONCENTRATIONS (ppb) AT SOME US PWRs

	Condensate Polishing[a]	Condenser Material[b]	Feedwater Heater Material[b]	Reheater Material	Condensate	Polished Condensate	High Pressure Drains	Moisture Separator Drains	Feedwater	Blowdown
Recirculating Steam Generator Systems										
Calvert Cliffs 1	None	70/30 CuNi	SS	90/10 CuNi	0.5	NA[c]	--	--	0.4	10
	PRF	70/30 CuNi	SS	90/10 CuNi	0.4	--	--	--	0.3	15
Ginna	DB	Admiralty	Copper Alloy	90/10 CuNi	--	--	--	--	--	--
Prairie Island 1	None	SS	SS	CS	0.02	NA	0.17	--	0.1	7
	PRF				--	--	--	--	--	--
Prairie Island 2	None	SS	SS	CS	0.09	NA	0.15	0.5	0.3	16
	PRF				--	--	--	--	--	--
Surry 2	None	90/10 CuNi	Copper Alloy	90/10 CuNi	0.2	NA	0.5	--	0.4	11
Trojan	PRF	Admiralty	Copper Alloy	90/10 CuNi	--	--	--	--	0.2	--
Turkey Point 4	None	Alum. Brass	Copper Alloy	90/10 CuNi	0.2	NA	--	--	1.5	60
St. Lucie 1	None	Titanium	Admiralty SS	90/10 CuNi	0.05	NA	0.19	--	0.21	--
Millstone 2	DB	70/30 CuNi	Copper Alloy SS	90/10 CuNi	0.30	0.06	--	--	--	5.0
Once-through Steam Generator Systems										
ANO-1	DB	Admiralty	SS	90/10 CuNi	0.2	0.03	0.6	0.9	0.6	NA
Crystal River 3	DB	70/30 CuNi	SS	90/10 CuNi	0.6	0.07	0.4	--	0.5	NA
Oconee 1	PRF	SS	SS, CS	CS	<0.07	<0.07	0.2	0.6	0.2	NA

a) PRF = Powdered Resin Precoat Filters
DB = Deep Beds

b) SS = Stainless Steel
CS = Carbon Steel

c) NA = Not Applicable

Note: St. Lucie 1, see ref. 7
Millstone 2, see ref. 8
Other power plants, see ref. 2

TABLE 4.5

(a) SUMMARY OF STEADY STATE IRON AND COPPER CONCENTRATION (ppb) AT SOME PWRs

Plant	Condensate		Polished Condensate		Intermediate Feedwater		H.P. Heater Drains		Moisture Separation Drains		Feedwater		Blowdown		Ref.
	Fe	Cu	Fe	Cu	Fe	Cu	Fe	Cu	Fe	Cu	Fe	Cu	Fe	Cu	
Indian Point 2	13.1	4.9			12.9	13.5	10.0	15.4			11.1	19.5			11
Fort Calhoun 1	9.1	0.2			9.3	3.8	9.6	0.02			10.5	1.54	54.0	2.9	9
Beaver Valley 1	1.39	0.03									6.4	0.03	27.0	0.59	9
Prairie Island 2															9
(Ammonia)	4.94				9.34		7.11				7.39		394.0		
(Morpholine)	2.15				2.97		3.92				3.3		51.0		
Point LePreau	2.23				14.40				6.13		2.82		807.1		12
A Japanese Plant	9.0	1.1	3.0	<0.2	5.0	<0.2			28.0		13.0				16
Beznau	1.3	0.5							18.0	0.4	4.1	0.4			17

(b) SUMMARY OF STEADY STATE IRON, COPPER AND NICKEL CONCENTRATION (ppb) AT ANO-2 & BRUCE 2

Plant	Condensate			Intermediate Feedwater			H.P. Heater Drains			Moisture Separation Drains			Feedwater			Blowdown			Ref.
	Fe	Cu	Ni	Fe	Cu	Ni	Fe	Cu	Ni	Fe	Cu	Ni	Fe	Cu	Ni	Fe	Cu	Ni	
ANO-2																			10
(Ammonia)	9.2	1.8	0.1	9.8	1.2	0.2	8.5	0.2	0.3	11.4	0.1	0.3	4.9	0.6	0.08	27.8	4.9	0.9	
(Boric Acid)	9.6	2.2	0.2	8.3	2.1	0.2	9.8	2.3	0.4				3.1	0.6	0.2	21.0	2.5	0.5	
Bruce 2	14.0	6.0	2.0	14.0	9.0	3.0							15.0	12.0	8.0	140.0	30.0	15.0	14

TABLE 4.6

COMPARISON OF CORROSION PRODUCT FORM (PERCENT FILTERABLE) OF ELEMENTS IN SAMPLES COLLECTED IN SOME PWR SECONDARY SYSTEMS

Plant	Condensate			Intermediate Feedwater			H.P. Heater Drain			Feedwater			Blowdown			Ref.
	Fe	Cu	Ni	Fe	Cu	Ni	Fe	Cu	Ni	Fe	Cu	Ni	Fe	Cu	Ni	
ANO-2	99	92	77	68	96	40	60	95	34	67	97	50	95	98	99	10
Beaver Valley	97	73								84	67		89	98		9
Fort Calhoun	97	90		93	99		41	100		54	99		97	100		9
Prairie Island																9
(Ammonia)	99			99			64			74			99			
(Morpholine)	97			99			66			67			94			
Point LePreau	97			99			44			85			99			12

TABLE 4.7
CORROSION PRODUCT FORM (Percent Filterable) OF ELEMENTS IN SAMPLES COLLECTED IN FEEDTRAIN OF SCOG STUDY PLANTS

Plant	Period	Condensate			Polished Condensate			High Pressure Drains			Feedwater			Blowdown		
		Iron	Copper	Nickel	Iron	Copper	Nickel	Iron	Copper	Nickel	Iron	Copper	Nickel	Iron	Copper	Nickel
Prairie Island 1	Oct - Dec 1976	98	-	70	-	-	-	69	-	44	78	-	83	99	-	98
	July 1977	98	-	47	-	-	-	-	-	-	89	-	62	99	-	98
	Sept - Nov 1978	97	-	70	72	-	54	-	-	-	-	-	-	-	-	-
Prairie Island 2	Aug - Sept 1976	98	-	69	-	-	-	53	-	50	84	-	83	-	-	-
	Dec/77 - Feb 1978	96	-	66	72	-	39	-	-	-	-	-	-	-	-	-
	Jan - July 1979	95	-	63	66	-	-	-	-	-	-	-	-	-	-	-
Surry 2	Oct - Nov 1975	98	87	80	-	-	-	39	92	-	77	96	63	99	98	99
	Jan - Feb 1977	-	-	-	-	-	-	98	97	84	98	96	78	99.9	99.8	99.8
Trojan	Jan 1979	97	99	96	82	59	81	99	99	98	94	97	82	-	-	-
	Feb - Apr 1979	99	90	49	60	21	10	44	92	39	19	82	16	-	-	-
Turkey Point 4	July - Sept 1975	89	84	91	-	-	-	-	-	-	80	27	81	99.8	97	99.4
Ginna	Jan - June 1980	99	81	-	86	61	-	-	-	-	-	-	-	-	-	-

TABLE 4.8

COMPARISON OF STEADY STATE IRON TRANSPORT (g/h) AT SOME US PWRs

Power Plant	Condensate Polishing [a]	Condenser Material [b]	Feedwater Heater Material [b]	Reheater Material	Condensate	Polished Condensate	High Pressure Drains	Moisture Separator Drains	Feedwater	Blowdown	Blowdown Efficiency %
Recirculating Steam Generator Systems											
Calvert Cliffs 1	None	70/30 CuNi	SS	90/10 CuNi	38	NA[c]	-	-	61	7.5	12.3
	PRF	70/30 CuNi	SS	90/10 CuNi	39	-	-	-	48	7.1	14.8
Ginna 1	DB	Admiralty	Cu Alloy	90/10 CuNi	32	4.6	-	-	-	-	-
Prairie Island 1	None	SS	SS	CS	22	NA	16.0	-	36	4.4	12.2
	PRF				12	0.5	-	-	-	-	-
Prairie Island 2	None	SS	SS	CS	24	NA	6.5	5.9	40	18.2	45.5
	PRF				12	0.6	-	-	-	-	-
Surry 2	None	90/10 CuNi	Cu Alloy	90/10 CuNi	34	NA	14.0	-	52	5.9	14.8
Trojan	PRF	Admiralty	Cu Alloy	90/10 CuNi	50	0.5	28.0	-	27	-	-
Turkey Point 4	None	Alum. Brass	Cu Alloy	90/10 CuNi	42	NA	-	-	64	16.4	25.6
St. Lucie 1	None	Titanium	Admiralty/SS	90/10 CuNi	27	NA	22.0	-	43	-	-
Millstone 2	DB	70/30 CuNi	Cu Alloy/SS	90/10 CuNi	32	8.6	-	-	-	0.3	-
Once-through Steam Generator Systems											
ANO-1	DB	Admiralty	SS	90/10 CuNi	43	7.4	28.0	16.0	40	NA	-
Crystal River 3	DB	70/30 CuNi	SS	90/10 CuNi	46	12.8	6.5	-	48	NA	-
Oconee 1	PRF	SS	SS/CS	CS	16	1.2	9.1	10.4	23	NA	-

a) PRF = Powdered Resin Precoat Filters
DB = Deep Beds

b) SS = Stainless Steel
CS = Carbon Steel

c) NA = Not Applicable

Note:

St. Lucie 1, see ref. 7
Millstone 2, see ref. 8
Other Power Plants, see ref. 2

180026-L4-RD

TABLE 4.9
COMPARISON OF STEADY STATE COPPER TRANSPORT (g/h) AT SOME US PWRs

Power Plant	Condensate Polishing [a]	Condenser Material [b]	Feedwater Heater Material [b]	Reheater Material	Condensate	Polished Condensate	High Pressure Drains	Moisture Separator Drains	Feedwater	Blowdown	Blowdown Efficiency %
Recirculating Steam Generator Systems											
Calvert Cliffs 1	None	70/30 CuNi	SS	90/10 CuNi	2.5	NA[c]	-	-	2.0	0.4	20.0
	PRF	70/30 CuNi	SS	90/10 CuNi	2.1	-	-	-	2.4	0.4	16.7
Ginna 1	DB	Admiralty	Cu Alloy	90/10 CuNi	1.8	0.2	-	-	-	-	-
Prairie Island 1	None										
	PRF	SS	SS	CS	NA	NA	NA	NA	NA	NA	-
Prairie Island 2	None										
	PRF	SS	SS	CS	NA	NA	NA	NA	NA	NA	-
Surry 2	None	90/10 CuNi	Cu Alloy	90/10 CuNi	4.9	NA	2.2	-	7.9	0.3	3.8
Trojan	PRF	Admiralty	Cu Alloy	90/10 CuNi	11.4	1.5	1.7	-	2.4	-	-
Turkey Point 4	None	Alum. Brass	Cu Alloy	90/10 CuNi	6.7	NA	-	-	6.2	0.5	8.1
St. Lucie 1	None	Titanium	Admiralty/SS	90/10 CuNi	0.63	NA	0.30	-	0.69	-	-
Millstone 2	DB	70/30 CuNi	Cu Alloy/SS	90/10 CuNi	4.0	0.73	-		-	0.03	-
Once-through Steam Generator Systems											
ANO-1	DB	Admiralty	SS	90/10 CuNi	10.3	0.12	0.4	0.17	1.45	NA	-
Crystal River 3	DB	70/30 CuNi	SS	90/10 CuNi	4.3	0.25	0.4	-	0.45	NA	-
Oconee 1	PRF	SS	SS/CS	CS	<0.4	<0.2	0.15	0.13	<0.3	NA	-

a) PRF = Powdered Resin Precoat Filters
DB = Deep Beds

b) SS = Stainless Steel
CS = Carbon Steel

c) NA = Not Applicable

Note:

St. Lucie 1, see ref. 7
Millstone 2, see ref. 8
Other Power Plants, see ref. 2

TABLE 4.10
COMPARISON OF STEADY STATE NICKEL TRANSPORT (g/h) AT SOME US PWRs

Power Plant	Condensate Polishing a	Condenser Material b	Feedwater Heater Material b	Reheater Material	Condensate	Polished Condensate	High Pressure Drains	Moisture Separator Drains	Feedwater	Blowdown	Blowdown Efficiency %
Recirculating Steam Generator Systems											
Calvert Cliffs 1	None	70/30 CuNi	SS	90/10 CuNi	1.9	NA c	-	-	2.0	0.2	10.0
	PRF	70/30 CuNi	SS	90/10 CuNi	1.3	-	-	-	1.4	0.3	21.4
Ginna 1	DB	Admiralty	Cu Alloy	90/10 CuNi	-	-	-	-	-	-	-
Prairie Island 1	None	SS	SS	CS	0.04	NA	0.16	-	0.33	0.1	30.3
	PRF				-	-	-	-	-	-	-
Prairie Island 2	None	SS	SS	CS	0.20	NA	0.14	0.13	1.0	0.2	20.0
	PRF				-	-	-	-	-	-	-
Surry 2	None	90/10 CuNi	Cu Alloy	90/10 CuNi	0.54	NA	0.7	-	1.8	0.3	16.7
Trojan	PRF	Admiralty	Cu Alloy	90/10 CuNi	-	-	-	-	1.4	-	-
Turkey Point 4	None	Alum. Brass	Cu Alloy	90/10 CuNi	0.61	NA	-	-	7.0	1.1	15.7
St. Lucie 1	None	Titanium	Admiralty/SS	90/10 CuNi	0.18	NA	0.30	-	1.1	-	-
Millstone 2	DB	70/30 CuNi	Cu Alloy/SS	90/10 CuNi	1.2	0.24	-	-	-	0.15	-
Once-through Steam Generator Systems											
ANO-1	DB	Admiralty	SS	90/10 CuNi	0.74	0.12	0.8	0.23	3.0	NA	-
Crystal River 3	DB	70/30 CuNi	SS	90/10 CuNi	2.2	0.25	0.4	-	2.1	NA	-
Oconee 1	PRF	SS	SS/CS	CS	<0.2	<0.2	0.2	0.17	1.2	NA	-

a) PRF = Powdered Resin Precoat Filters
DB = Deep Beds

b) SS = Stainless Steel
CS = Carbon Steel

c) NA = Not Applicable

Note:

St. Lucie 1, see ref. 7
Millstone 2, see ref. 8
Other Power Plants, see ref. 2

TABLE 4.11

SUMMARY OF STEADY STATE IRON & COPPER TRANSPORT RATE (g/h) AT SOME PWRs

Plant	Condensate		Intermediate Feedwater		H.P. Heater Drain		Moisture Separation Drain		Feedwater		Blowdown		Blowdown Efficiency (%)		Ref.
	Fe	Cu	Fe	Cu	Fe	Cu	Fe	Cu	Fe	Cu	Fe	Cu	Fe	Cu	
ANO-2															
(Ammonia)	18.4	3.5	19.6	2.4	6.94	0.17	2.86	0.03	13.9	1.7	0.63	0.11	4.5	6.5	10
(Boric Acid)	19.2	4.4	16.6	4.2	8.04	1.88			8.8	1.8	0.49	0.05	5.6	2.8	
Fort Calhoun															
(Amp)	18.6	0.4	17.5	7.2	7.1	0.02			29.3	4.5	0.48	0.03	1.6	0.7	9
Beaver Valley															
(Morpholine)	3.9	0.08							28.0	0.12	1.13	0.02	4.0	16.7	9
Prairie Island															
(Ammonia)	11.3		21.2		6.5				23.5		13.6		57.8		
(Morpholine)	4.9		6.8		3.5				10.3		1.9		18.5		9
Point LePreau															
(Ammonia)	5.91		39.1		4.4		2.3		9.9		1.2		12.1		12
Benzau (1983)	0.76				0.79		1.5		4.2						17

TABLE 4.12

IRON AND ZINC TRANSPORT DATA AT POINT LEPREAU NGS
(Sampling Period, May 1-18, 1985)

★ Sample Number	Sample Location	Date	Time (Hours)	Volume (Litres)	* System Flowrate (kg/sec)	Total Iron (ppb)	Total Iron (grams/hr)	Percent Filterable Iron (%)	Total Zinc (ppb)	Total Zinc (grams/hr)	Percent Filterable Zinc (%)
1A	CEP	5/1-2/85	0900-0830	84.40	676.96	86.02	209.63	99.86	1.49	3.64	83.33
2A	LP HTR #3 Out	5/1-2/85	0900-0830	69.50	676.96	4.46	10.87	96.77	0.30	0.74	9.52
3A	BFP Discharge	5/1-2/85	0900-0830	82.60	986.96	25.97	92.27	97.90	0.40	1.42	72.73
4A	HP HTR-Out	5/1-2/85	0900-0830	79.90	986.96	31.75	112.82	94.60	0.19	0.67	86.67
5A	SG Blowdown #2**	5/1-2/85	0900-0830	74.30	0.46	11978	19.87	-	62.00	0.10	-
6A	SG Blowdown #4**	5/1-2/85	0900-0830	39.10	0.48	36317	63.11	-	166.00	0.29	-
7A	Reheater Drains	5/1-2/85	0900-0830	68.80	51.06	4.46	0.82	72.40	0.58	0.11	45.00
8A	MSD	5/1-2/85	0940-1030	46.80	92.51	12.74	4.24	67.11	0.13	0.04	50.00
9A	HP HTR Drains	5/1-2/85	0940-1030	46.10	209.14	15.16	11.42	79.83	0.24	0.18	54.55
1B	CEP	5/2-3/85	1020-0815	54.40	680.45	10.22	25.04	89.93	0.11	0.27	33.33
2B	LP HTR #3 Out	5/2-3/85	1020-0815	94.70	690.45	1.19	2.92	82.30	0.30	0.72	3.57
3B	BFP Discharge	5/2-3/85	1020-0815	67.90	965.20	10.40	36.13	92.07	0.25	0.87	29.41
4B	HP HTR Out	5/2-3/85	1020-0815	70.30	965.20	11.27	39.15	86.87	0.13	0.44	55.56
5B	SG Blowdown #2**	5/2-3/85	1020-0815	45.50	0.48	23077	40.08	-	114.00	0.20	-
6B	SG Blowdown #4**	5/2-3/85	1020-0815	61.70	0.50	12642	22.74	-	78.00	0.14	-
7B	Reheater Drains	5/2-3/85	1020-0815	58.60	84.60	3.34	1.02	60.20	0.44	0.14	34.62
8B	MSD	5/2-3/85	1100-0945	82.90	90.00	9.72	3.15	51.24	0.17	0.05	21.43
9B	HP HTR Drains	5/2-3/85	1100-0945	80.80	203.75	8.33	6.11	61.37	0.16	0.12	38.46
1C	CEP	5/10/85	1550-2300	40.80	524.00	492.33	928.73	99.47	6.30	11.68	97.28
2C	LP HTR #3 Out	5/10/85	1550-2300	34.30	524.00	33.03	62.31	98.23	0.50	0.93	58.82
3C	BFP Discharge	5/10/85	1550-2300	29.40	767.00	177.72	490.72	99.52	1.19	3.29	94.29
4C	HP HTR Out	5/10/85	1550-2300	34.20	767.00	173.92	480.22	99.19	0.99	2.75	97.06
5C	SG Blowdown #2**	5/10/85	1550-2300	30.50	0.48	8852	15.38	-	75.00	0.13	-
6C	SG Blowdown #4**	5/10/85	1550-2300	77.40	0.50	8398	15.11	-	101.00	0.18	-
7C	Reheater Drains	5/10/85	1550-1854	9.50	84.60	6.63	2.02	44.44	0.53	0.16	40.00
8C	MSD	5/10/85	1550-2058	8.80	90.00	50.91	16.49	85.49	0.80	0.26	57.14
9C	HP HTR Drains	5/10/85	1550-2058	11.00	203.75	363.45	266.59	98.80	3.82	2.80	90.48
1D	CEP	5/17-18/85	1945-0820	31.40	362.00	271.94	354.40	99.54	4.71	6.14	94.59
2D	LP HTR #3 Out	5/17-18/85	1945-0820	39.30	362.00	29.13	37.97	95.02	0.79	1.03	70.97
3D	BFP Discharge	5/17-18/85	1945-0820	29.60	529.00	338.11	642.68	99.30	3.85	7.32	94.74
4D	HP HTR Out	5/17-18/85	1945-0820	49.80	528.00	261.75	497.53	99.73	2.51	4.77	98.40
5D	SG Blowdown #2**	5/17-18/85	1945-0820	16.40	0.53	53657	102.38	-	506.00	0.97	-
6D	SG Blowdown #4**	5/17-18/85	1945-0820	30.80	0.54	17859	34.71	-	198.00	0.39	-
7D	Reheater Drains	5/17/85	0750-1310	17.00	84.60	11.35	3.46	87.05	1.06	0.32	38.89
8D	MSD	5/18/85	0920-1310	12.90	90.00	139.77	45.28	77.37	4.57	1.48	23.73
9D	HP HTR Drains	5/18/85	0920-1310	16.80	203.75	73.51	53.92	97.17	0.77	0.57	61.54

* Flowrates based on information provided by Point Lepreau personnel.

** Filterable material was present on both the membrane filter and cation resin membrane on these samples. Therefore, the membranes were combined as one sample for analysis.

★ System condition during sample collection:
A - Reheater testing, minor flow variations in system
B - Steady load operation right after reheater testing
C - Shutdown
D - Startup

TABLE 4.13
IRON TRANSPORT DATA AT POINT LEPREAU NGS
(January - April, 1986)

Test Phase	Sample Location	Date	Sample Flowrate (kg/sec)	...erable* Iron (ppb)	Non-Filterable* Iron (ppb)	Total Iron (ppb)	Total Iron (grams/hr)	Filterable Iron (%)
11/84	Low Pressure Heater #3 Outlet	11/8-12/84	754.3	14.3	0.1	14.4	39.1	99.3
	High Pressure Heater Outlet	11/8-12/84	951.6	2.3	0.4	2.7	9.3	85.2
	Reheater Drains	11/8-12/84	82.6	0.7	0.4	1.1	0.3	63.6
	Moisture Separator Drains	11/8-12/84	89.9	3.1	3.9	7.0	2.3	44.3
	High Pressure Heater Drains**	11/8-12/84	202.5	2.7	3.4	6.1	4.4	44.3
1	Low Pressure Heater #2 Outlet	1/1-30/86	754.3	3.0	0.5	3.5	9.5	85.7
	High Pressure Heater Outlet	1/1-30/86	951.6	5.3	3.0	8.3	28.4	63.8
	Reheater Drains	1/1-30/86	82.6	2.7	1.2	3.9	1.2	69.2
	Moisture Separator Drains	1/1-30/86	89.9	5.5	11.9	17.4	5.6	31.6
	High Pressure Heater Drains**	1/1-30/86	202.5	5.8	7.9	13.7	9.9	42.3
2	Low Pressure Heater #2 Outlet	1/30-2/24/86	754.3	20.0	0.6	20.6	55.9	97.1
	High Pressure Heater Outlet	1/30-2/24/86	951.6	6.2	4.3	10.5	35.9	59.1
	Reheater Drains	1/30-2/24/86	82.6	2.9	2.1	5.0	1.5	58.0
	Moisture Separator Drains	1/30-2/24/86	89.9	5.0	23.4	28.4	9.2	17.6
	High Pressure Heater Drains**	1/30-2/24/86	202.5	7.8	18.9	26.7	19.5	29.2
3	Low Pressure Heater #2 Outlet	2/24-3/26/86	754.3	15.0	1.0	16.0	43.4	93.7
	High Pressure Heater Outlet	2/24-3/26/86	951.6	4.5	2.9	7.4	25.4	60.8
	Reheater Drains	2/24-3/26/86	82.6	2.6	1.9	4.5	1.4	57.8
	Moisture Separator Drains	2/24-3/26/86	89.9	3.5	5.9	9.4	3.0	37.2
	High Pressure Heater Drains**	2/24-3/26/86	202.5	5.1	4.8	9.9	7.2	51.51
4	Low Pressure Heater #2 Outlet	3/26-4/18/86	754.3	15.0	2.0	17.0	46.1	88.2
	High Pressure Heater Outlet	3/26-4/18/86	951.6	6.0	1.7	7.7	26.4	77.9
	Reheater Drains	3/26-4/18/86	82.6	4.9	0.8	5.7	1.7	86.0
	Moisture Separator Drains	3/26-4/18/86	89.9	3.1	2.0	5.1	1.7	60.8
	High Pressure Heater Drains**	3/26-4/18/86	202.5	3.9	1.9	5.8	4.2	67.2

* Reported values are averages of several (4 - 6) integrated samples collected during the indicated sample period.

** HP heater drains sample taken from HP heater drain A only. It is assumed HP heater drain A and B will have similar concentration. The flow rate values reflect total HP heater drain flow.

Test Phase	Water Chemistry Condition
1	Reduce residual concentration of hydrazine to 10 - 20 µg/kg, but maintain feedwater pH at 9.5 with ammonia addition.
2	Maintain residual hydrazine concentration at 10 - 20 µg/kg, but reduce feedwater pH to 9.2 using ammonia.
3	Maintain residual hydrazine concentration at 10 - 20 µg/kg, and feedwater pH at 9.2, using morpholine addition.
4	Maintain residual hydrazine concentration at 10 - 20 µg/kg, and increase feedwater pH to 9.5 via morpholine addition.

TABLE 4.14

AVERAGE SECONDARY SYSTEM CORROSION PRODUCT CONCENTRATIONS AT PRAIRIE ISLAND

Location	Iron, ppb							
	Ammonia Control				Morpholine Control			
	F	NF	Total	Filterable Fraction %	F	NF	Total	Filterable Fraction %
Condensate	4.90	0.04	4.94	99	2.08	0.07	2.15	97
Intermediate Feedwater	9.28	0.06	9.34	99	2.93	0.04	2.97	99
Feedwater	5.45	1.94	7.39	74	2.20	1.1	3.30	67
Heater Drain Pump	4.55	2.56	7.11	64	2.57	1.35	3.92	66
Blowdown	392.00	2.00	394.00	99	48.00	3.0	51.00	94

F = Filterable
NF = Non-Filterable

TABLE 4.15

AVERAGE SECONDARY SYSTEM CORROSION PRODUCT TRANSPORT RATES AT PRAIRIE ISLAND

Location	Iron, grams/h	
	Ammonia Control	Morpholine Control
Condensate	11.3	4.9
Intermediate Feedwater	21.2	6.8
Feedwater	23.5	10.3
Heater Drain Pump	6.5	3.5
Blowdown	13.6	1.9
Buildup in Steam Generator*	9.9	8.4

* Feedwater Input - Blowdown Removal

TABLE 5.1

Comparison of Crud and Iron Concentrations in Two Locations at Gentilly 2 and Point Lepreau

	Gentilly 2 (no hydrazine)	Point Lepreau (100-200 ppb hydrazine)
HP Heater Outlet		
Crud* (ppb)	1-4	2.5
Iron (ppb)	5	2.8
Boiler Blowdown		
Crud* (ppb)	10-300	600-2000
Iron (ppb)	5-40	600-2000

* Normal operations only. During transient, values up to 260 ppb have been recorded.

Added Comments

There appears to be some contradictions in the above results/28/:

(1) The iron concentration in the HP heater of both Gentilly 2 and Point Lepreau are higher than the crud (suspended solids) concentration; yet iron is only one of the constituents in the crud.

(2) The blowdown iron and crud concentrations in Point Lepreau are the same. This happens if metallic iron is the only corrosion product, which is very unlikely.

TABLE 5.2

REDUCTION OF CORROSION PRODUCT TRANSPORT (g/h) BY CONDENSATE TREATMENT IN SOME PWR STUDY PLANTS

Plant		Polisher inlet	Polisher Outlet	Feedwater		Feedwater Transport Decrease with Polishers, %
				with Polishing[a]	Without Polishing[b]	
Iron	ANO-1	43	7.4	40	76	47
	Crystal River 3	46	12.8	48	81	41
	Oconee 1	16	1.2	23	38	39
	Trojan	50	0.49	27	76	65
	Prairie Island 1	11.6	0.5	25[c]	36[d]	31
	Prairie Island 2	12.3	0.6	28[c]	40[d]	30
Copper	ANO-1	10.3	1.15	1.45	10.6	86
	Crystal River 3	4.3	0.94	0.45	3.8	88
	Oconee 1	<0.4	<0.1	<0.3	<0.7	-
	Trojan	11.4	1.46	2.4	12.3	81
Nickel	ANO-1	0.74	0.12	3.0	3.6	17
	Crystal River 3	2.23	0.25	2.12	4.1	48
	Oconee 1	<0.2	<0.2	1.2	<1.4	<15
Zinc	Trojan	10.7	2.35	9.9	18.2	46

a) Measured except where noted
b) Calculated except where noted
c) Calculated
d) Measured

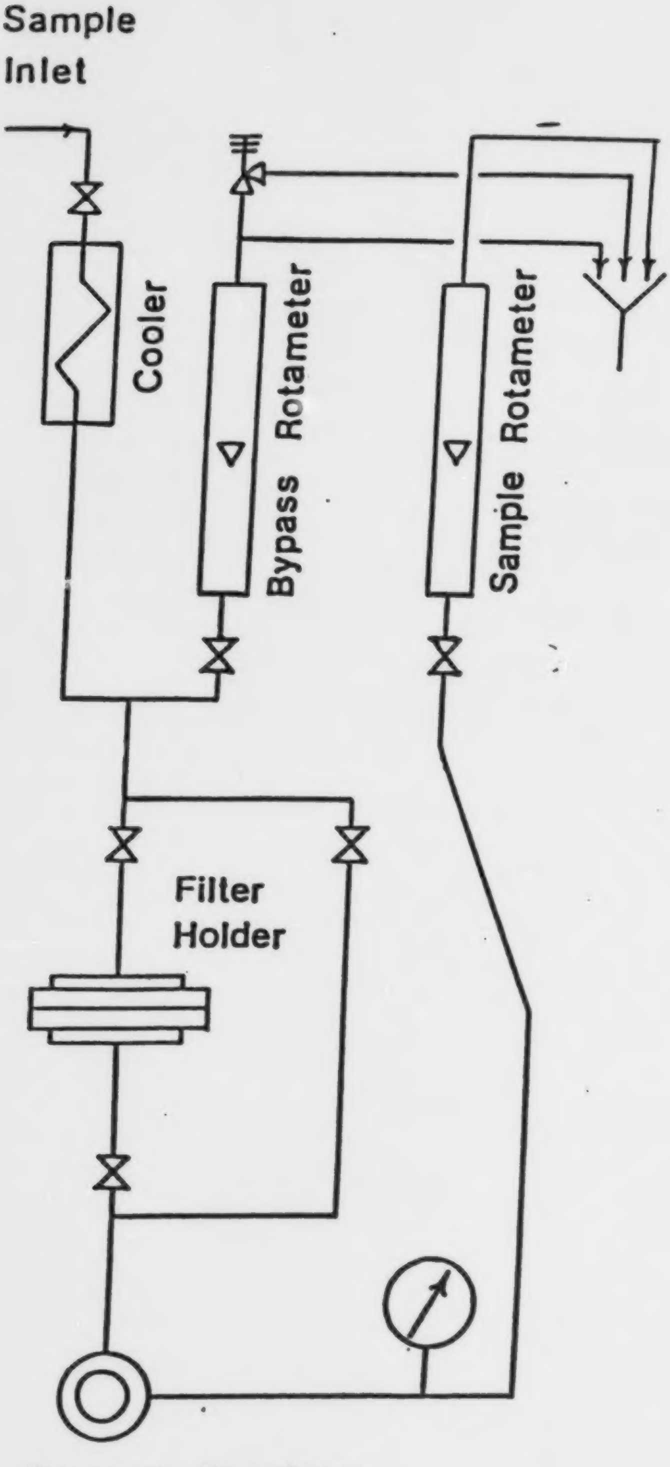

Sample
Inlet
Cooler
Bypass Rotameter
Sample Rotameter
Filter
Holder
Pressure Regulator

FIGURE 3.1

SCHEMATIC DIAGRAM OF AN INTEGRATED SAMPLING SYSTEM
DESIGNED BY NWT CORPORATION (REF. 2)

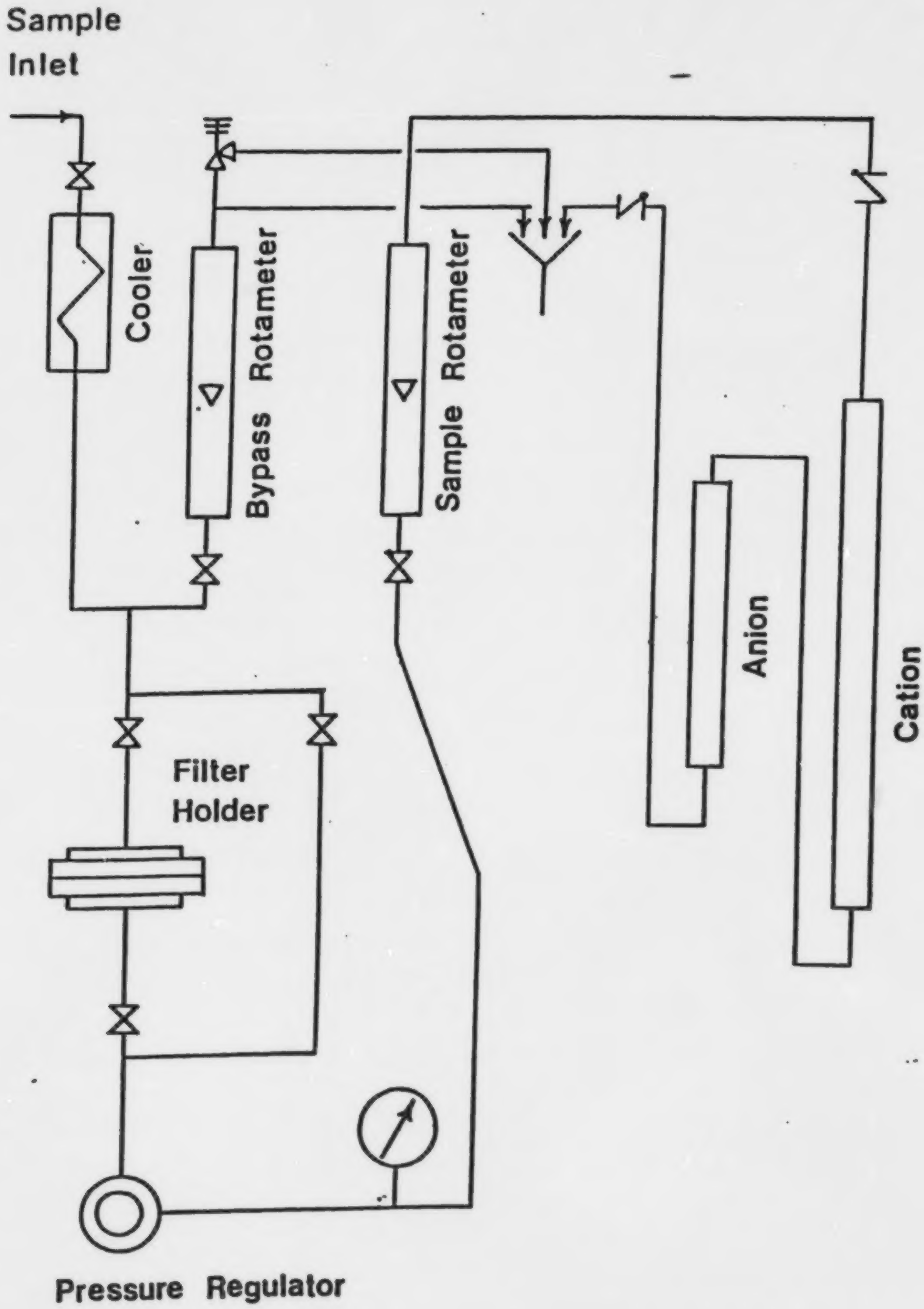

Sample Inlet
Cooler
Bypass Rotameter
Sample Rotameter
Anion
Cation
Filter Holder
Pressure Regulator

FIGURE 3.2

A MODIFICATION OF THE SAMPLING SYSTEM DESIGNED BY NWT CORPORATION (REF. 2)

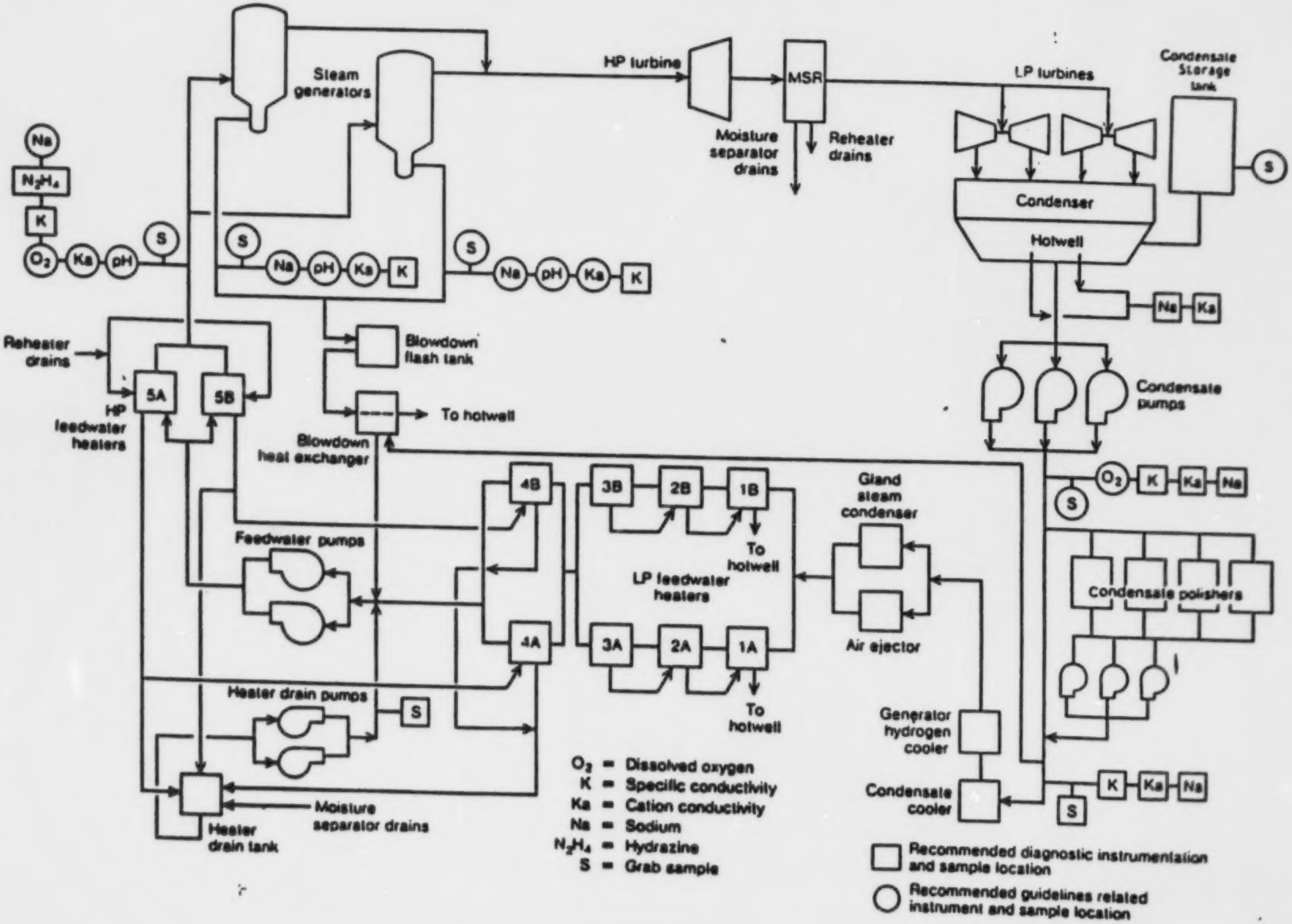
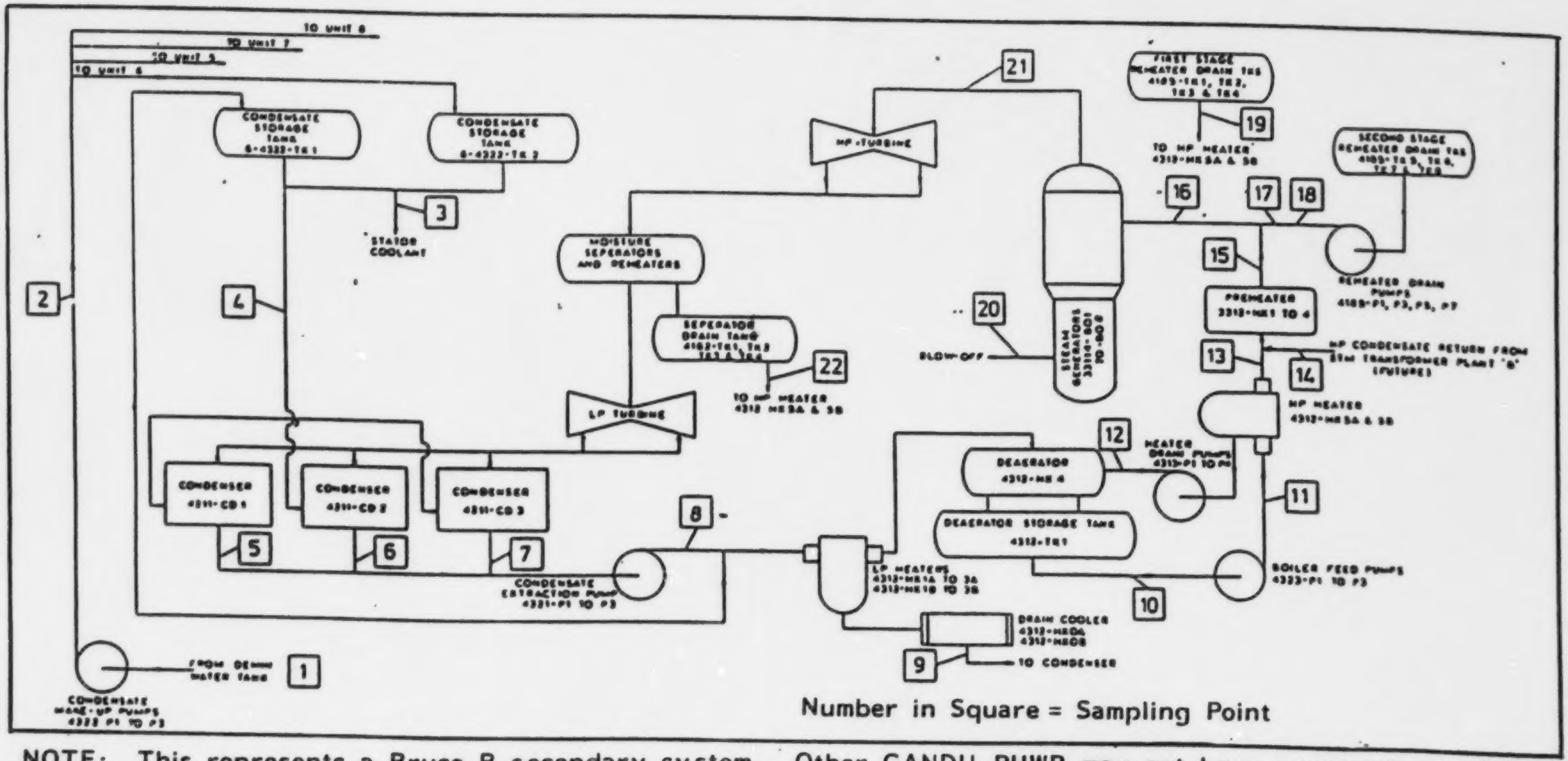

Steam generators
HP turbine
MSR
Moisture separator drains
Reheater drains
LP turbines
Condensate Storage tank
S
Condenser
Hotwell
Na
N_2H_4
K
O_2
Ka
pH
S
Na
pH
Ka
K
S
Na
pH
Ka
K
Na
Ka
Reheater drains
5A
5B
HP feedwater heaters
Blowdown flash tank
To hotwell
Blowdown heat exchanger
Condensate pumps
O_2
K
Ka
Na
S
4B
3B
2B
1B
To hotwell
Gland steam condenser
Feedwater pumps
LP feedwater heaters
Condensate polishers
4A
3A
2A
1A
To hotwell
Air ejector
Heater drain pumps
S
Generator hydrogen cooler
Condensate cooler
K
Ka
Na
S
Moisture separator drains
Heater drain tank
O_2 = Dissolved oxygen
K = Specific conductivity
Ka = Cation conductivity
Na = Sodium
N_2H_4 = Hydrazine
S = Grab sample
Recommended diagnostic instrumentation and sample location
Recommended guidelines related instrument and sample location

FIGURE 3.3

SCHEMATIC OF A TYPICAL RECIRCULATING PWR SECONDARY SYSTEM (REF. 4)


TO UNIT 8
TO UNIT 7
TO UNIT 5
TO UNIT 6
CONDENSATE STORAGE TANK 0-4322-TK 1
CONDENSATE STORAGE TANK 0-4322-TK 2
STATOR COOLANT
MOISTURE SEPERATORS AND REHEATERS
SEPERATOR DRAIN TANK 4102-TK1, TK2 TK3 & TK4
TO HP HEATER 4312 HE 5A & 5B
LP TURBINE
HP-TURBINE
CONDENSER 4311-CD 1
CONDENSER 4311-CD 2
CONDENSER 4311-CD 3
CONDENSATE EXTRACTION PUMP 4321-P1 TO P3
FROM DEMIN WATER TANK
CONDENSATE MAKE-UP PUMPS 4322 P1 TO P3
LP HEATERS 4312-HE1A TO 3A 4312-HE1B TO 3B
DRAIN COOLER 4312-HE0A 4312-HE0B
TO CONDENSER
DEAERATOR 4312-HE 4
DEAERATOR STORAGE TANK 4312-TK1
HEATER DRAIN PUMPS 4312-P1 TO P4
BOILER FEED PUMPS 4323-P1 TO P3
HP HEATER 4312-HE 5A & 5B
HP CONDENSATE RETURN FROM STM TRANSFORMER PLANT 'B' (FUTURE)
PREHEATER 3312-HX1 TO 4
REHEATER DRAIN PUMPS 4103-P1, P3, P5, P7
SECOND STAGE REHEATER DRAIN TKS 4103-TK 5, TK 6, TK 7 & TK 8
FIRST STAGE REHEATER DRAIN TKS 4103-TK1, TK2, TK3 & TK4
TO HP HEATER 4312-HE 5A & 5B
STEAM GENERATORS 33110-BO1 TO BO8
BLOW-OFF
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22

Number in Square = Sampling Point

NOTE: This represents a Bruce B secondary system. Other CANDU-PHWR may not have a separate pre-heater.

FIGURE 3.4

SCHEMATIC OF A CANDU-PHWR SECONDARY SYSTEM (REF. 5)

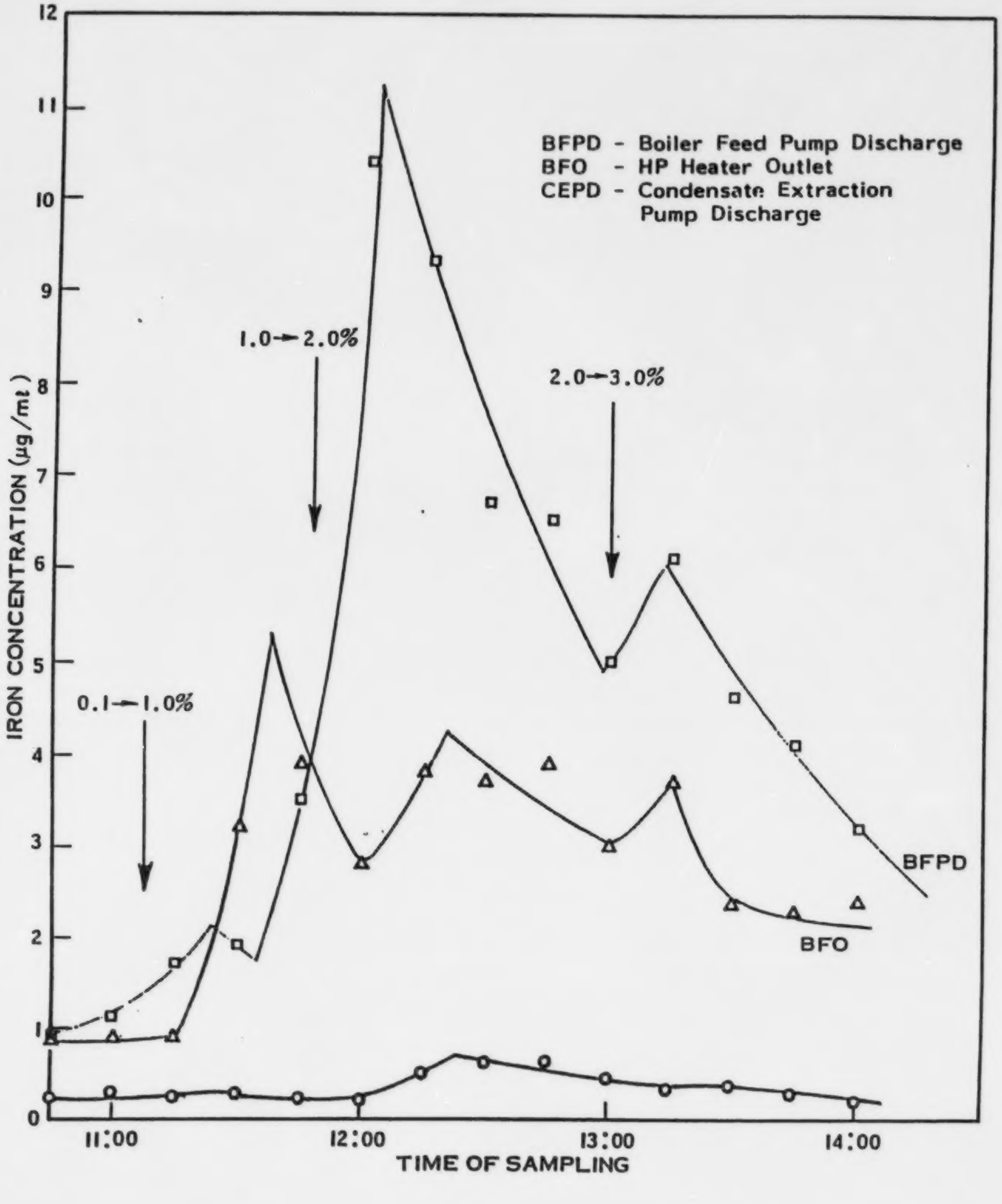


FIGURE 4.1

IRON IN FEEDWATER OF BRUCE A UNIT 2 DURING REACTOR POWER INCREASE FROM 0.1 TO 3 PERCENT, AUG 28/76

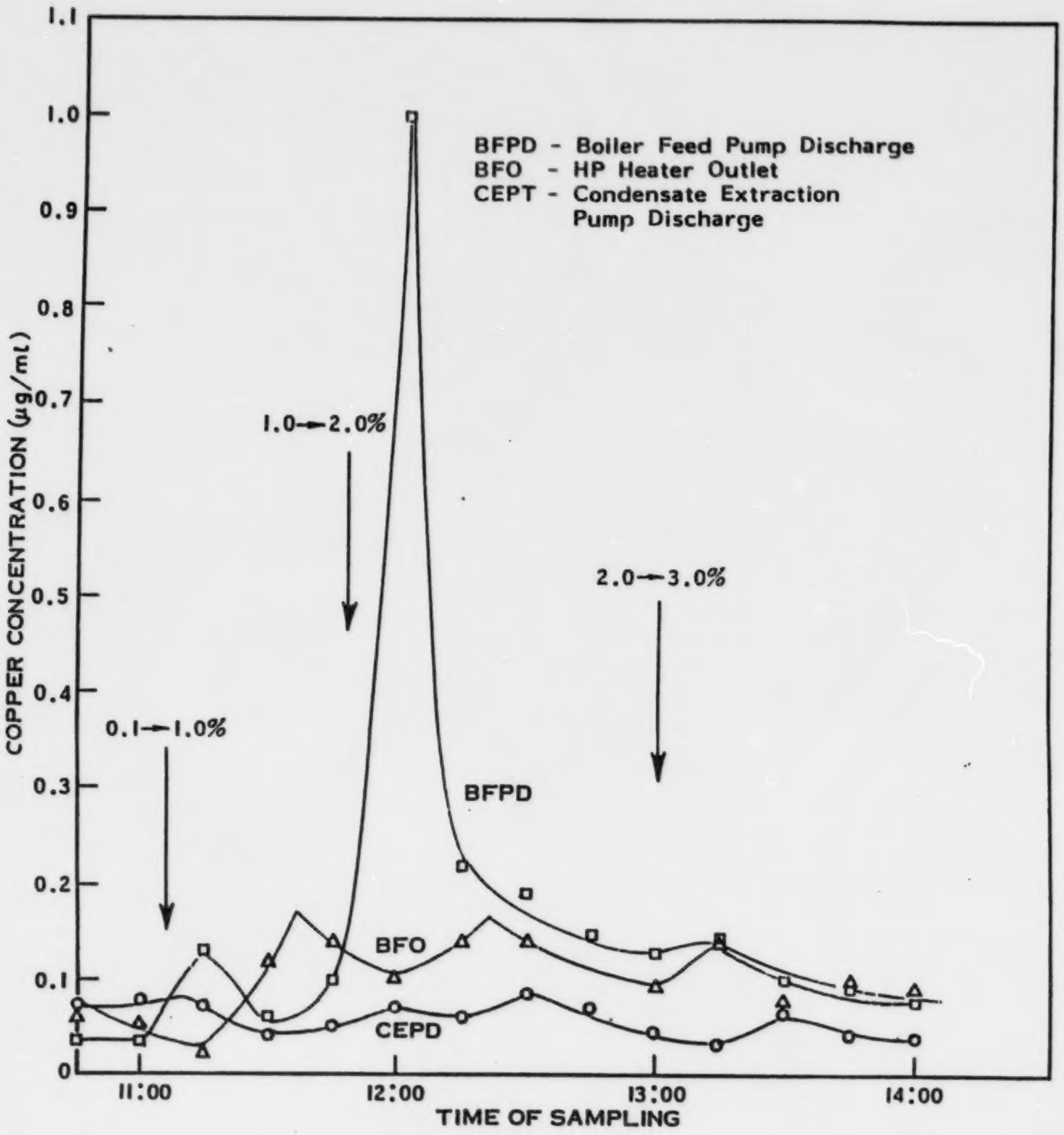
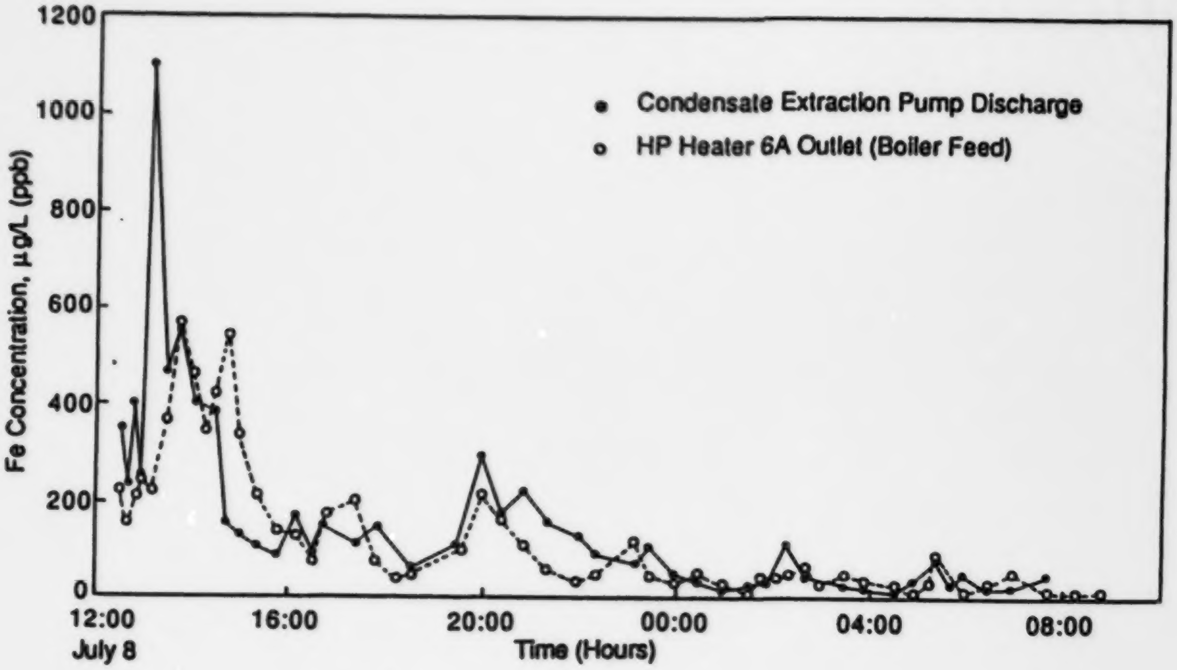


FIGURE 4.2

COPPER IN FEEDWATER OF BRUCE A UNIT 2 DURING REACTOR POWER INCREASE FROM 0.1 TO 3 PERCENT, AUG 28/76



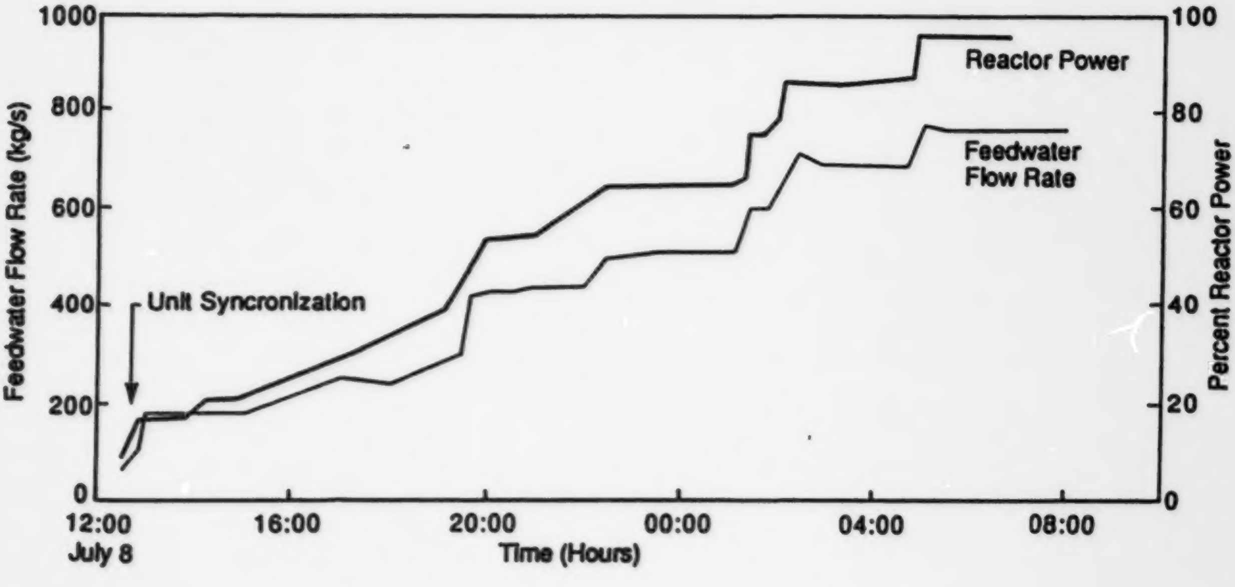
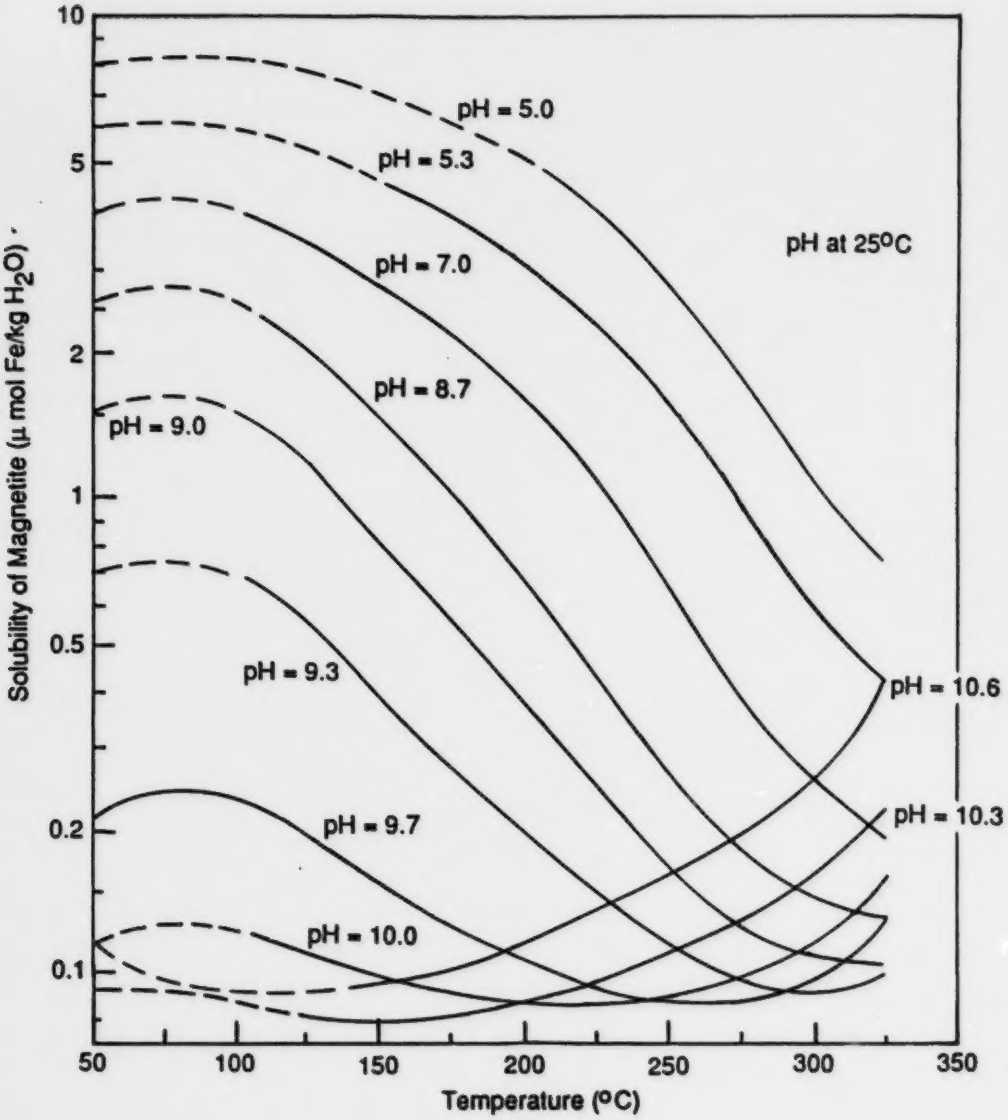


FIGURE 4.3

IRON CONCENTRATION IN THE SECONDARY SYSTEM
OF PICKERING-2 ON JULY 8, 1980 (Ref. 13)



Note:
(1) All curves are generated at 18 cc/kg H_2O dissolved hydrogen
(2) ppb Fe = 55 x µ mol Fe

FIGURE 4.4

SOLUBILITY OF MAGNETITE VERSUS WATER TEMPERATURE AND pH (Ref. 18)

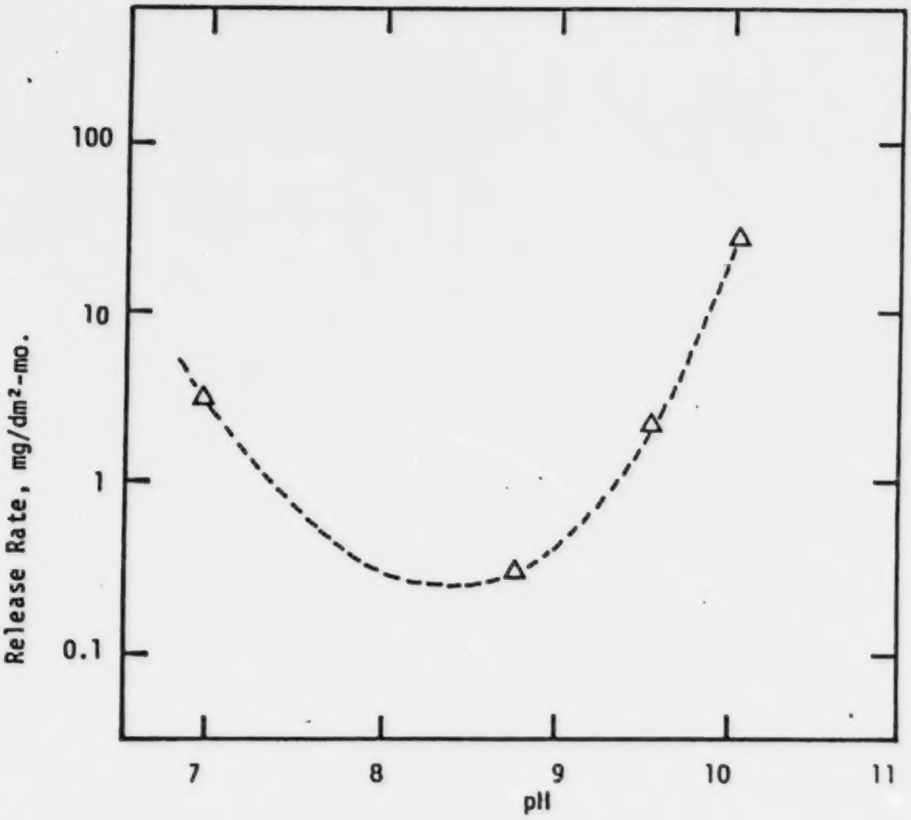


FIGURE 4.5

EFFECT OF pH ON CORROSION PRODUCT RELEASE RATE FROM ALLOY 706 (90/10 COPPER NICKEL) (REF. 19)

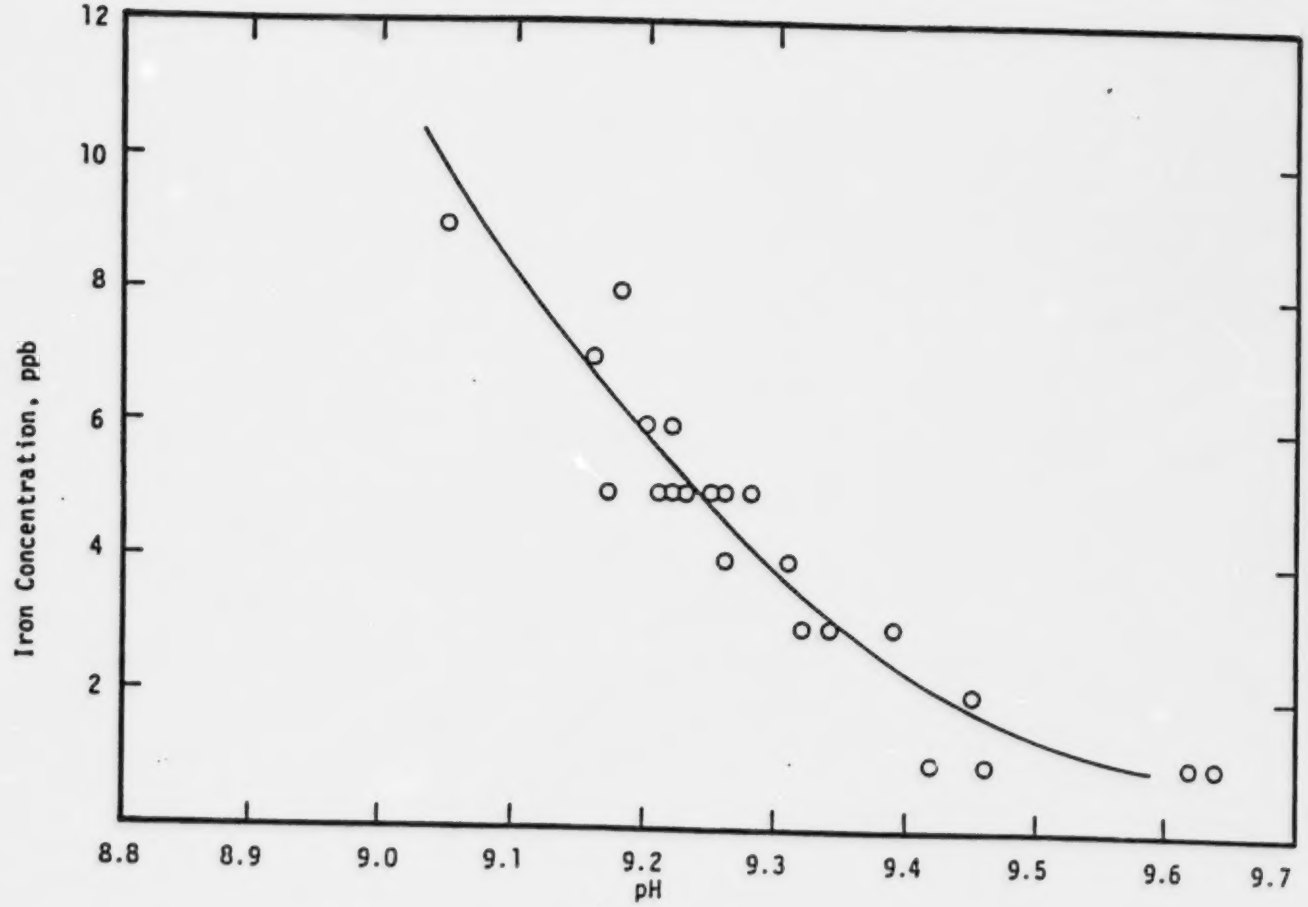


FIGURE 4.6

EFFECT OF pH ON IRON CONCENTRATION AT THE ECONOMIZER INLET-CRANE STATION (REF. 20)

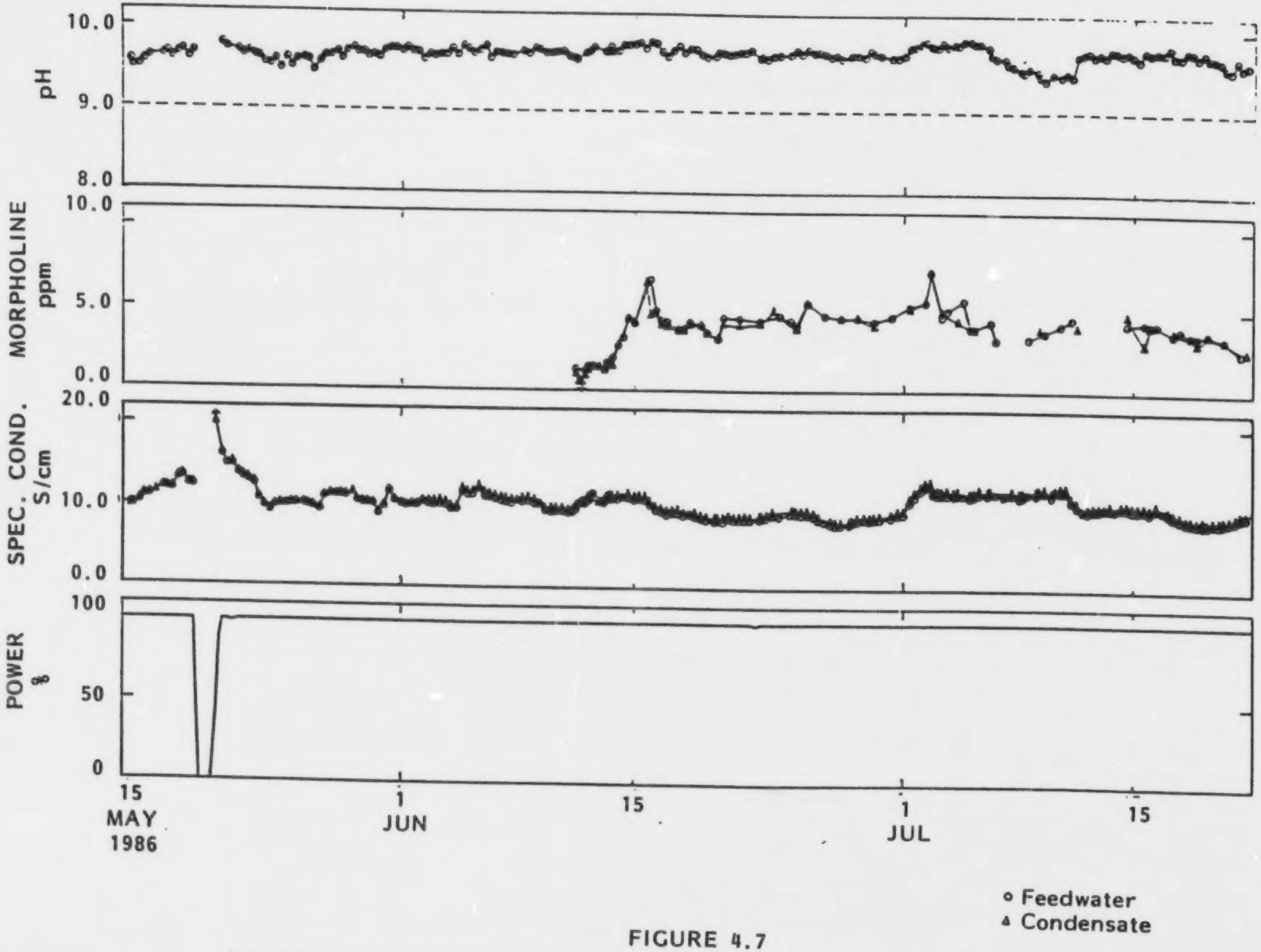


FIGURE 4.7
CONDENSATE AND FEEDWATER CHEMISTRY AT PRAIRIE ISLAND 2 (Ref. 9)

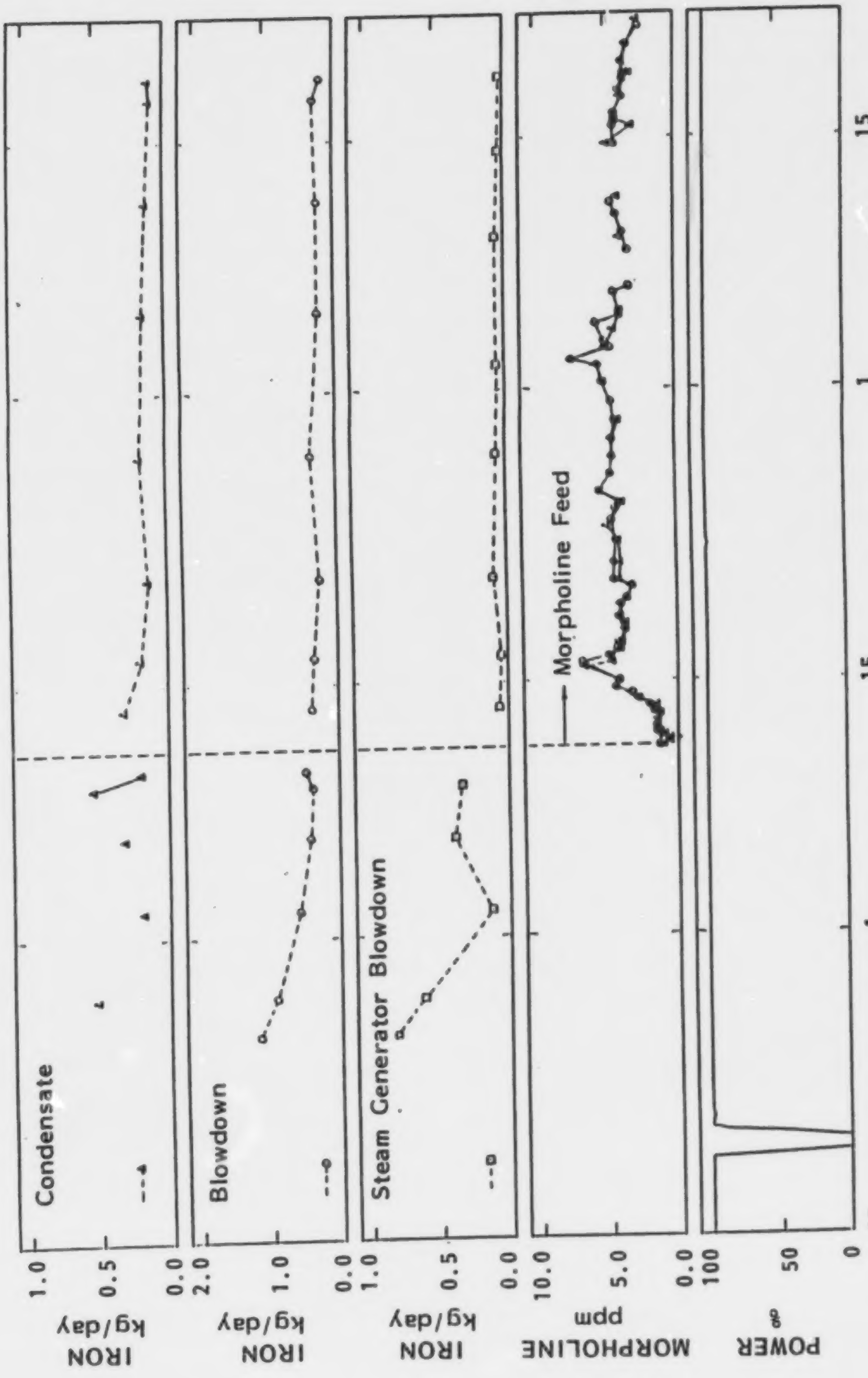


FIGURE 4.8
EFFECT OF MORPHOLINE FEED ON IRON TRANSPORT AT PRAIRIE ISLAND 2 (Ref. 9)

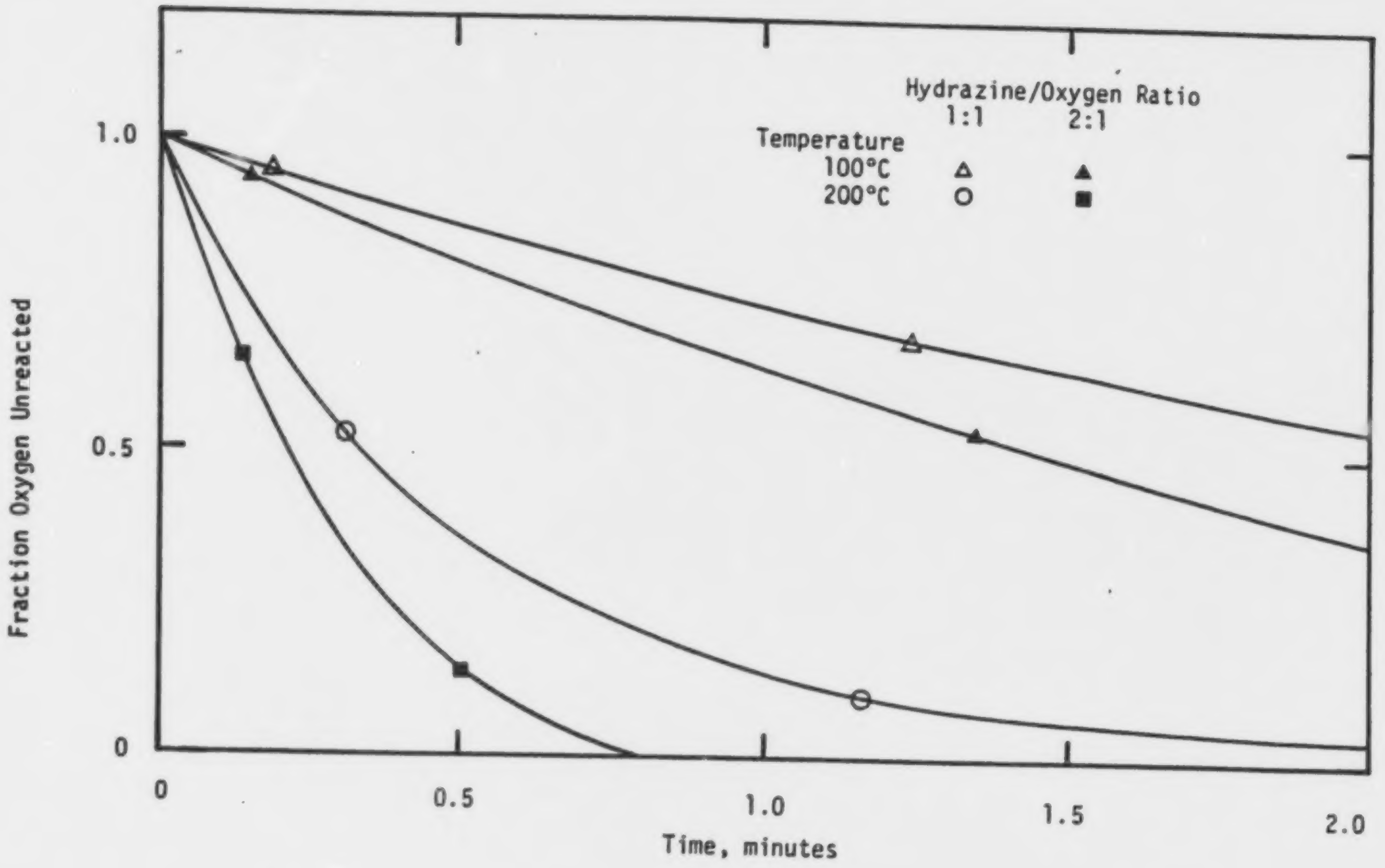


FIGURE 5.1

REACTION TIME OF HYDRAZINE WITH OXYGEN AT 2 TEMPERATURES AND DOSAGES (REF. 27)

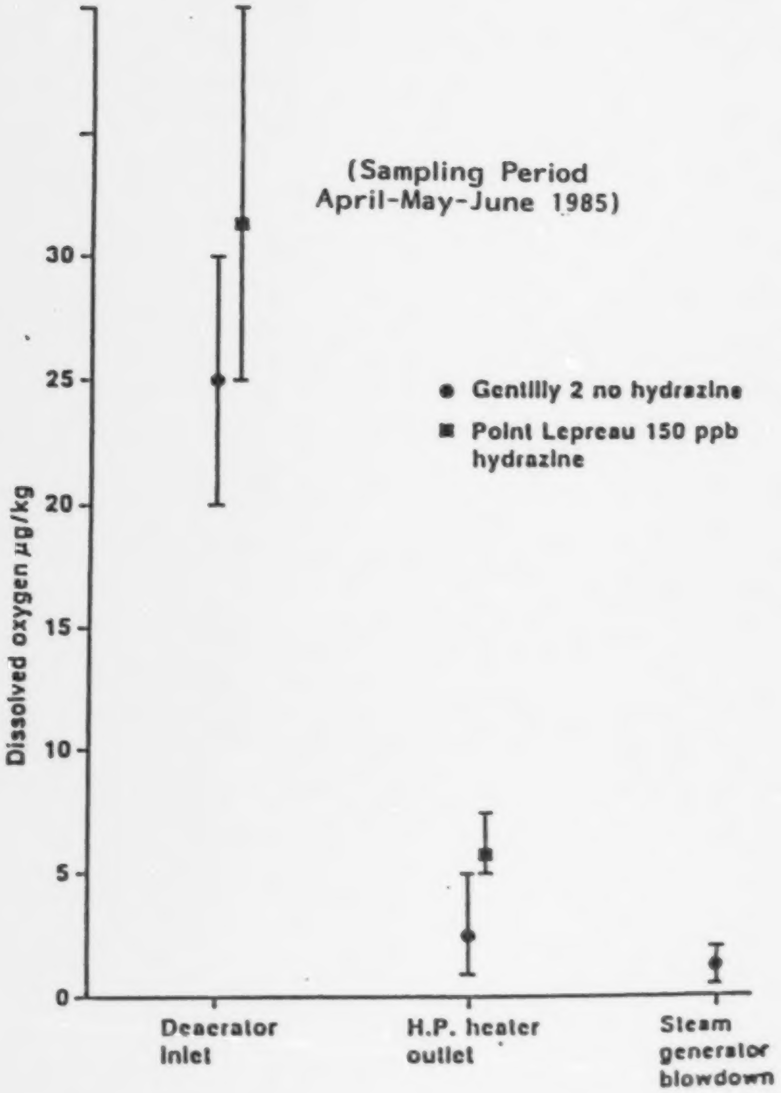


FIGURE 5.2

DISSOLVED OXYGEN IN THE GENTILLY 2
AND POINT LEPREAU FEEDWATER SYSTEMS
(REF. 28)

APPENDIX A

Result Summary of Utility Surveys

This appendix summarizes the results of the surveys discussed in the main body of this report. For convenience, the experiences of the utilities are grouped together by country. A reference section is included at the end.

A.1 Survey of US Utilities

A.1.1 Steam Generator Owners Group Utilities

Feedtrain Design and Water Chemistry Operating History:

This survey/A-1/ included 10 nuclear power plants. These plants may be divided into 2 groups:

i) Plants (7) with recirculating steam generator system

Calvert Cliffs 1
Ginna
Prairie Island 1 and 2
Surry 2
Trojan
Turkey Point 4

ii) Plants (3) with once-through steam generator system

Arkansas Nuclear One 1 (ANO-1)
Crystal River 3
Oconee 1

As far as corrosion product transport is concerned, the difference between these 2 types of steam generator systems is the blowdown system. The once-through steam generator system does not have continuous blowdown during normal operation and all of the feedwater corrosion product burden can be considered to be deposited in the steam generators.

A brief description of the design characteristics of the 10 secondary systems/A-1,A-2/ is summarized in Table A.1.1. These plants use AVT water chemistry with ammonia as the pH control additive. However, significant variations in construction materials, feedwater pH, etc. exist between these plants, for example:

- Oconee 1 and Prairie Island 1 and 2 are all-ferrous systems and operate at a pH of 9.2 to 9.6.

- Calvert Cliffs 1, ANO-1 and Crystal River 3 have all-ferrous feedwater heaters and copper alloy condenser and reheaters, with the feedwater pH at 8.5 to 9.0.

- Ginna, Surry 2, Trojan and Turkey Point 4 employ copper alloys throughout the cycle, and operate at a feedwater pH 8.5 to 9.0.

Although most of these plants have condensate treatment facilities, they may not be in use during sampling, for example: at Turkey Point 4, and Surry 2, and Calvert Cliffs. Other plant designs that may affect corrosion product transport include:

- Crystal River 3 has a full-flow deaerating heater.

- Oconee 1 operates with both low temperature and high temperature forward drain pumping while other study plants employ only high temperature forward drain pumping.

Objectives:

1) to quantify corrosion product transport to the steam generators; and

2) to identify major corrosion product sources.

Result Summary:

Corrosion product concentrations during steady state operation and the overall average concentrations (steady state plus transients) are summarized in Tables A.1.2 to A.1.13. Based on these results the following observations were made:

- Corrosion products in transport came predominantly from the condenser. The inputs from the high pressure heater drains and moisture separator drains were also significant.

- Corrosion product transport rates are plant specific. The overall transport rates (ie., including transients) are higher than those during steady load operation; eg., in Prairie Island 2, iron increased by 37%; in Calvert Cliffs 1 and Surry 2, copper increased by 75%; in Calver Cliffs 1, nickel increased by 60%.

- As currently designed, steam generator continuous blowdown is not an effective technique for removing feedwater corrosion product input to the steam generators. Overall blowdown removal efficiency for iron ranged from 9% to 38%, Copper from 6% to 11%, and nickel from 8% to 26%. Removal efficiencies during steady state operation were somewhat higher.

- Total iron accumulation could reach 500-600 kg/year in recirculating steam generators. Total copper accumulation varied with plant design and were in the order of 50-100 kg/year at units with copper condenser and feedwater heaters.

- Feedwater corrosion product transport rates to the steam generators are lower in all-ferrous alloy systems with pH at 9.3 to 9.6 compared with mixed alloy systems with pH maintained at 8.5 to 9.2 eventhough the ferrous alloy surface area is significantly less in mixed alloy systems. This is likely due to a higher corrosion rate of the system materials at pH 8.5 to 9.2. The feedwater pH is a compromise since secondary systems with mixed alloy metallurgy cannot minimize the corrosion rate of either carbon steel or copper alloy without increasing the corrosion rate of the other to an unacceptable level.

- Nickel input to the steam generators is increased significantly if the high pressure feedwater heater tubes are made of Monel rather than stainless steel, 80/20 or 90/10 copper nickel.

- Feedwater iron transport to the steam generators can be reduced by 30% to 50% by full-flow condensate treatment. Similarly, average copper and nickel inputs can be reduced by 75% to 90% and 20% to 50%, respectively.

- The filterable fraction of the corrosion products (see Table A.1.14) varies with locations and between sampling periods. For iron, over 89% in the condensate and at least 99% in the blowdown were filterable; but significant variations occurred in other locations particularly in the high pressure heater drains. At plants with condensate treatment, the percentage filterable iron was reduced substantially at the demineralizer outlet (similarly for other elements). Copper in transport was in filterable form (over 80%, except at the demineralizer outlet and at Turkey Point 4 feedwater). Most of the nickel in transport was in filterable form with a lower percentage than that of iron for corresponding sampling periods.

A.1.2 St. Lucie No. 1

Feedtrain Design and Water Chemistry Operating History:

The nuclear steam supply system of St. Lucie 1 is a Combustion Engineering design (817 MWe). The unit went commercial in December 1976. The feedtrain uses mixed alloy metallurgy and the feedwater uses AVT chemistry with ammonia as the pH control additive/A-3/.

After only 17 months of commercial operation, denting was observed and the following retrofit was made:

- In May 1979, the condenser was retubed with titanium and an integrally grooved tube sheet was installed.
- In May 1980, heaters number 3, 4 and 5 were retubed with stainless steel.
- In December 1981, heaters number 1 and 2 and the drain coolers were retubed with stainless steel (the retube was done after this sampling study).

Objective:

1) to monitor corrosion product transport as part of the baseline data for feedwater chemistry.

Result Summary:

Samples were collected at the HP heater outlet, condensate pump discharge, HP heater drains, and 3B heater outlet during steady state operation from April through August 1981. The average corrosion product concentrations and transport rates are summarized in Table A.1.15 and A.1.16, respectively.

- Copper and zinc transport in the condensate resulted from routing the Admiralty tubed LP heater drains to the condenser.
- The iron concentration in the HP heater drain was the highest and its contribution to final feedwater iron transport was significant.
- Significant zinc pickup across the LP heaters was observed.
- Some dropout of copper occurred along the feedtrain.

- During the course of the sampling study, a large air leak developed at the turbine boot, but no significant changes in corrosion product transport was observed. The air leak was estimated to last over a week in August, 1981 with condensate dissolved oxygen level at about 20 ppb. However, no details were given in the report/A-3/.

A.1.3 Millstone 2

Feedtrain Design and Water Chemistry Operating History:

Millstone 2 went into commercial operation in December 1975 and was rated at 828 MWe(net). The secondary system uses mixed alloy metallurgy and AVT ammonia chemistry/A-4/.

- In April 1977, the condenser, which was tubed originally with aluminum brass, was retubed with 70/30 copper nickel as a result of frequent condenser cooling water in leakage.

- In May 1977, after 16 months of commercial operation, denting was observed.

- In April 1978, full-flow deep bed condensate polishing was implemented to assist in further reducing impurity levels throughout the system.

- In April 1979, 2 low pressure feedwater heaters were retubed with stainless steel.

Objective:

1) to determine the effects of the retrofits and system modifications by monitoring the corrosion product transport.

Result Summary:

Only 3 sampling points were used. Samples were collected at the condensate demineralizer inlet and outlet from July 1980 through April 1981 and at the steam generator blowdown from February 1981 through April 1981. Samples were analyzed for iron, copper, nickel and zinc. Average corrosion product concentrations and mass transport rates are summarized in Table A.1.17 and A.1.18.

- Average removal efficiencies of the demineralizer for iron, copper, nickel,and zinc were 73%, 82%, 80%, and 50%, respectively.

- The demineralizer removed approximately 62 Kg of iron and 9 Kg of copper during steady state operation over the 2600-hour monitoring period.

- Blowdown removed a maximum of 4% of the iron and copper introduced into the steam generators.

A.1.4 Arkansas Nuclear One Unit 2 (ANO-2)

Plant Design and Operating Water Chemistry History:

ANO-2 is a Combustion Engineering-designed PWR, 912 MWe(net). Commercial operation began in March 1980. The recirculating steam generators are equipped with Alloy 600 tubes. The feedwater circuit uses mixed alloy metallurgy/A-5/. Since startup, the secondary cycle uses all volatile treatment ammonia water chemistry. However, feedwater pH, impurity levels, condensate oxygen concentrations varied significantly during the first fuel cycle. Control of these parameters improved during the second fuel cycle. The plant operated within the Steam Generator Owners Group secondary chemistry guidelines approximately 95% of the time, but feedwater pH continued to be a problem. Also, the steam generators showed severe denting at the upper drilled support plates/A-6/. In extensive laboratory tests, boric acid was found to be capable of arresting or slowing denting progression/A-7/. Arkansas Power & Light Company decided to implement boric acid treatment at ANO-2 during the third fuel cycle. With the addition of boric acid, secondary water chemistry specifications were amended as shown in Table A.1.19.

Objective:

1) to quantify corrosion product transport in the secondary cycle before and after boric acid treatment;
2) to identify major sources of corrosion products; and
3) to quanitfy the effect of boric acid addition on the rate of hydrogen generation in the steam generators.

Since objective #3 is outside the scope of this review, the results will not be discussed here.

Result Summary:

Baseline corrosion product transport data were obtained prior to the initiation of boric acid treatment. However, the amount of data obtained during boric acid treatment was limited because of an early plant shutdown for refueling and maintenance.

a) Corrosion Product Transport Before Boric Acid Treatment

The average corrosion product concentrations and transport rates (during steady state operation) in the secondary system are given in Figures A.1 and A.2. The results are summarized as follows:

- The condensate system was the major source of iron and copper.
- Feedwater iron transport remained approximately constant across the first four low pressure heaters. Iron transport decreased substantially across the high pressure heaters (#1 and 2), indicating deposition of iron at steady-state operation. There appears to be some inconsistencies in the iron concentrations and transport rates across the high pressure heaters. For example, the feedwater iron concentration decreased by about 15% from heater #4 to heater #2 with input from the reheater drains (see Figure A.1) yet in Figure A.2, the corresponding iron transport rate actually increased by about 20%. This is not possible since transport rate is directly proportional to corrosion product concentration. No flow rates were given in the report.
- Copper transport appeared to decrease along the feedwater heaters indicating deposition of copper.
- The pump-forward heater drains contributed 20 to 30% of the total feedwater iron transport, but only 10% of the copper.
- Less than 10% of the corrosion product ingress to the steam generators was removed by blowdown.
- The iron concentration in the moisture separator drains was high, second only to that of the blowdown.

b) Corrosion Product Transport After Boric Acid Treatment

After completing 4 days of operation at 25% reactor power for boric acid conditioning, an unscheduled outage delayed the resumption of corrosion product sampling. This delay, combined with an early shutdown for refueling and maintenance, limited the data obtained during operation with boric acid (2 sets of samples covering a 13 day period). The average corrosion product concentrations and transport rates are shown in Figures A.3 and A.4. The results show:

- Copper concentrations throughout the cycle were higher except in the final feedwater. The most significant increase occurred in the heater drain tank; 2.3 ppb vs 0.2 ppb, i.e., corrosion of the reheater tubing or heater #1, #2, or #3 shell-side heater tubing increased markedly as a result of boric acid addition.

- Copper deposition in the final 3 feedwater heaters increased sufficiently to compensate for increased corrosion in the first heaters. Final feedwater copper concentrations were nearly the same with or without boric acid addition.

- Increased iron deposition in the feedwater heaters, particularly in heater #3, led to a significant decrease in final feedwater iron transport rates.

- The proportion of filterable and non-filterable forms were roughly the same with or without the presence of boric acid (see Table A.1.20). Approximately 84% to 98% of the copper at all sample points was filterable. Greater than 95% of the condensate, blowdown, and heater 7A drain iron burden was filterable. At other locations, only 40% to 70% of the iron was filterable. Nickel followed a similar pattern as iron except the fraction of non-filterables was higher.

Although no formal explanation was suggested for the increase in copper concentrations in the cycle, it is suspected that a higher copper corrosion rate occurred because of:

1) lower feedwater pH, ie., 7.2-7.8 vs 8.5-9.2; and

2) additional amount of ammonia added to maintain feedwater pH (in the presence of boric acid).

A.1.5 Indian Point 2

Plant Design and Water Chemistry Operating History:

Indian Point 2 is an 873 MWe pressurized water reactor built by Westinghouse. Commercial power production begain in July 1973. The secondary system uses mixed alloy metallurgy/A-8/. Indian Point 2 has switched to all-volatile treatment (AVT) ammonia chemistry since May 1975. Since the changeover to AVT, steam generator blowdown pH generally has been maintained within the 8.5 to 9.0 specification by addition of hydrazine downstream of the condensate pump. Blowdown chloride level has been consistently less than 0.1 ppm. A schematic diagram of the secondary system is shown in Figure A.5.

Objective

1) to estimate the iron and copper transport in the condensate, feedwater, and the drain systems.

Result Summary:

The sampling study included several startups and a long period of steady full power operation, and the following results were observed:

- Most iron (over 80%) originated in the condenser and most copper from the water side of the feedtrain (see Figure A.6 to A.9).

- The average iron and copper transport rates were about 0.06 kg/h and 0.1 kg/h, respectively.

- Although the average iron concentrations in the feedtrain were within limits recommended in the EPRI PWR Secondary Water Chemistry Guidelines/4/, the average copper concentrations were well above the recommended limit of 2 ppb. (See Table A.1.21). This was likely due to the high dissolved oxygen concentrations in the feedtrain (see Table A.1.22).

- Significant deposition of iron in the HP heaters (ie., heaters 5 and 6) occurred.

- About 55% of the iron in the high pressure heater drain came from the fifth feedwater heater drain, and about 35% from the sixth heater drain (see Fig. A.10). Similarly, 40% of the copper in the high pressure heater drain originated from the fifth heater drain, and 45% from the sixth heater drain (see Fig. A.11). In both cases, the remainder came from the re-heater. However, in Figure A.10, there appears to be some discrepancies in the iron transport at the reheater drain, since the sum of the individual transports is much greater than the total.

- Between periods of injection of hydrazine, amerzine (a form of catalyzed hydrazine) and blank (ie., no injection), there were only minor differences in oxygen concnetration at different locations in the system with progressive higher temperatures (see Fig A.12). This showed that most of the oxygen was reacting with the feedwater heater materials rather than with hydrazine to give a final feedwater oxygen concentration of 1-2 ppb.

- During the August 1977 startup, very high copper release from heater #5 was observed.
- Over 90% of the iron and copper corrosion products were in particulate form.

A.1.6 Fort Calhoun 1 (490 MWe)

Feedtrain Design and Water Chemistry Operating History:

Fort Calhoun is a Combustion Engineering-designed PWR. Commercial operation commenced in September 1973. The secondary system uses mixed alloy metallurgy, eg., the condenser is tubed with 304 stainless steel, and copper alloys are used in the low pressure feedwater heaters. This unit had been operating intermittently with 2-amino-2-methyl-1-propanol and dimethylaminopropanol (AMP-DMAP) as an alternate to ammonia for several years/A-9/. During the study, routine analyses for AMP-DMAP were not performed. Based on the condensate TOC concentration attributable to AMP-DMAP, the maximum concentration of AMP-DMAP was estimated to be 0.4 ppm in the condensate. However, this could be an over estimate unless the degradation products were subtracted out. The average corrosion product concentrtions and transport rates are given in Tables A.1.23 and A.1.34.

Objectives:

1) to measure the effects of 2-amino-2-methyl-1-propanol (AMP) on corrosion product transport.
2) to measure the organic impurities in the secondary system resulting from the use of AMP.

Since the objective (2) is outside the scope of this review the results will not be discussed.

Result Summary:

- Approximately 65% of the total feedwater iron transport resulted from corrosion of condenser internals and LP heater extraction piping vented to the condenser. The remaining 35% appears attributable to erosion-corrosion of carbon steel moisture separator chevrons and possibly the high pressure extraction piping.
- Blowdown removed an insignificant fraction of the iron and copper transported to the steam generators.

- The major source of copper transported to the steam generators was tube-side corrosion of the LP heaters. Steam-side corrosion was negligible by comparison.
- Approximately 40% of the copper burden in the intermediate feedwater deposited in the high pressure feedwater heaters during steady power operation.
- The amount of filterable corrosion products varies with locations, eg., over 93% of the iron in condensate, LP heaters and blowdown was filterable, but dropped to 40-55% in the heater drains and final feedwater; for copper, over 90% was filterable throughout the feedtrain.
- Compared with ammonia, relatively high levels of acetate in the secondary system (eg, 2.9-7.6 vs 29-63 ppb) and cation conductivity in blowdown (0.3 vs 0.8 μS/cm) were observed.

A.1.7 Prairie Island 2 (520 MWe)

Feedwater Design and Water Chemistry Operating History:

Prairie Island 2 uses all-ferrous metallurgy in the secondary system. It had routinely operated with ammonia control at a pH near 9.6 and the corrosion product concentration has been relatively low (see section A.1.1). In an attempt to further reduce corrosion product transport, a transition was made to morpholine control (approximate morpholine concentration: 4 ppm) in June 1986. This section only reviews the average concentration data and transport rates in the 1986 study/A-9/.

Objective:

1) To measure the effects of morpholine on corrosion product transport in the secondary system.

Result Summary:

- Total iron concentrations and transportation rates at all locations in the cycle decreased by a factor of at least 2 with the transition to morpholine chemistry (see Tables A.1.25 and A.1.26).
- Although blowdown removal efficiencies were lower with the use of morpholine compared to ammonia, relatively large reduction in feedwater iron transport rates with morpholine led to a net reduction in sludge buildup rate (see Table A.1.26). Since the blowdown removal rate during ammonia operation was found to be higher than normal, the observed

reduction in sludge buildup in the steam generator was considered minimal.

- Morpholine appeared to increase the amount of non-filterables in some part of the feedtrain (compared with ammonia as pH control additive).
- Decomposition of morpholine led to increase in blowdown cation conductivity.

A.1.8 Beaver Valley 1 (852 MWe):

Feedtrain Design and Water Chemistry Operation History:

This is a Westinghouse-designed PWR/A-9/. During this study, the condensers, the LP and HP heaters were tubed with stainless steel, and the reheaters with 90/10 copper nickel. Beaver Valley has operated since initial startup with morpholine as the pH control additive. During the entire sampling campaign, feedwater morpholine concentration was maintained between 0.5 and 3 ppm.

Objective:

1) To study the effects of morpholine on corrosion product transport.

Result Summary:

The average concentration data and transport rates are shown in Tables A.1.27 and A.1.28, respectively.

- Iron transport by the condensate was approximately 15% of that observed in the feedwater.
- In general copper transport was low (0.08 to 0.12 g/h). Over half of the total copper transport observed in the feedwater resulted from transport via the condensate.
- The steam generator blowdown removed only a small fraction of the total corrosion product input to the steam generators.
- No significant sludge buildup has been observed on the steam generator tubesheets. (Plant personnel attributed this behaviour to the use of morpholine/A-10/. It is difficult to explain where the corrosion products are hiding since blowdown only removed a small fraction of the total input).
- Most of the iron and copper were in filterable form.

- Although preliminary results showed that morpholine reduced corrosion product transport at Beaver Valley further studies were suggested because:
  - i) morpholine concentration varied (from 0.5 to 3 ppm) during the study.
  - ii) the plant was undergoing a gradual power reduction, ie, a transient. Corrosion product concentrations during transients are higher than those during steady state operation.
  - iii) feedwater and blowdown iron concentrations might be biased high because the sample take-off point was located at the bottom of the process pipes.

A.2.0 Survey of Canadian Utilities

A.2.1 Point Lepreau

Feedtrain Design and Water Chemistry Operating History:

Point Lepreau NGS has a single CANDU 600 unit with a net capacity of 630 MWe/A-11/. The secondary system materials consist of Alloy 800 steam generator tubing, stainless steel tubed feedwater heaters with carbon steel shells, and a carbon steel moisture separator with high strength steel reheater tubing. The condenser is tubed with titanium and has an aluminum bronze condenser tubesheet. The condenser is cooled with seawater.

A deep bed condensate polishing system was retrofitted at Point Lepreau and was placed into service during the summer of 1986. With the installation of condensate polishers, system chemistry was changed to ammonia (pH 9.3 - 9.4) and hydrazine (10-20 g/kg), with low level phosphate injection (<10 ppm) to steam generators.

Objective:

1) To quantify the transport and determine the source of corrosion products in the secondary system.

Result Summary:

a) Corrosion Product Transport During Steady-State Operation

- Steady state total iron and total zinc concentrations (see Table A.2.1) in the condensate/feedwater cycle ranged between 1.8 to 3.3 ppb and 0.2 to 0.9 ppb, respectively.

- Greater than 82% of the iron in the feedwater was present in filterable form. The percent filterable zinc was generally lower than that of iron and covered a much wider range (28% to 81%). In the drains, the percent filterable iron and zinc were generally somewhat lower than those in the feedwater and blowdown.
- Significant release of iron occurred in the LP heaters (CEP iron at 2.23 ppb; LP heater iron at 14.4 ppb).
- The reheater drains contributed about 3% of the total iron and about 50% of the total zinc entering the steam generators.
- A maximum of 11 to 15 kg/yr of iron and 1.1 to 2.1 kg/yr of zinc were accumulating in each steam generator during steady state operation.
- Blowdown efficiencies ranged from 29% to 45% for iron and 5.4% to 7.7% for zinc.
- Iron and zinc corrosion products were accumulating in the deaerator. This was verified by deaerator inspection during maintenance outages.
- The zinc measured in the blowdown is likely the result of a zinc phosphate precipitate.

b) Corrosion Product Transport During Transients:

- Corrosion product concentrations increased substantially in the secondary system (see Table A.2.2) during shutdown and startup. In some streams, eg., condensate extraction pump discharge and HP heater drains, the iron concentration increased by 2 orders of magnitude, compared with those values at steady state operation.
- During shutdown and startup, a higher fraction of filterable iron and zinc was observed in the feedwater. The percent filterable iron was also higher in the drains.

c) Morpholine Water Chemistry Evaluation:

The retrofit of condensate polishers in 1986 at Point Lepreau NGS required some water chemistry changes due to the decomposition of hydrazine (to ammonia). Polisher efficiency decreases with increasing feedwater pH, ie., increasing ammonia concentration. Plant operating considerations in regard to polisher regeneration frequency dictated the necessity for lowering the feedwater pH to

9.3 - 9.4. Point Lepreau decided to substitute morpholine for ammonia as the pH control agent and the feedwater pH was reduced to 9.2. A sampling program was set up from January 1986 until April 1986. Preliminary results are shown in Table A.2.3.

The effects of morpholine chemistry on iron transport are:

- Morpholine addition appeared to reduce the iron transport in the moisture separator drain and the high pressure heater drain, ie., 2 phase regions.
- With morpholine, the iron concentration in the feedwater (HP heater outlet) was reduced somewhat (compared with ammonia) during the April 1986 sampling but these values are higher than those obtained during the November 1984 sampling.

A.2.2 Pickering NGS 'A' Unit 2

Feedtrain Design and Water Chemistry Operating History:

Pickering Unit 2 began production in December 1971. The secondary system uses mixed alloy metallurgy and the feedwater uses morpholine as pH control additive/A-12/. Boiler blowdown is not performed routinely. This survey was done in July, 1980.

Objective:

1) to measure corrosion product transport during steady full power operation and during startup.

Result Summary:

a) Steady State Full Power Operation

- Iron in the feedwater was less than 5 ppb and was essentially in particulate form (greater than 90%). Zinc in the feedwater was between 1 ppb and 2 ppb and was entirely in non-filterable form.
- Copper and nickel were not detectable in the feedwater but their presence was confirmed in boiler water.
- The Admiralty brass condenser and the LP heater tubes were the probable sources for zinc in transport.
- Iron in transport originated primarily in the condensate system. The all-ferrous reheater drains contributed less than 10% of the total iron ingress to the boilers.

- During a power rundown for a unit outage, there were no significant changes in feedwater corrosion product concentrations. (This appears to be contrary to other transport survey observations.)

b) Transport During Startup After a Prolonged Outage (56 days)

- Particulate iron from the condensate system comprised the bulk of the corrosion products in transport during a startup.

- Corresponding to ramp increase in reactor power and feedwater flow, there was a distinct spike in the concentration of particulate iron in both the condensate extraction pump discharge (CEPD) and HP heaters (see Fig. A.13). Feedwater iron concentrations would only return to steady load operation levels, ie., less than 5 ppb, 2 days after the unit had reached full power. However, boiler iron concentrations (boiler #7) were still at 2 ppm compared with 8-20 ppb during steady state.

- Zinc in transport was entirely non-filterable. Concentration differences suggested zinc was released from the Admiralty brass LP heaters downstream of the CEPD (see Fig. A.14).

- Although the copper and nickel in the feedwater were very low their concentrations in the boiler were estimated to be in the ppm range.

- Calcium levels (in non-filterable form) in CEPD and HP heaters were initially high during startup but dropped off sharply as reactor power was increased.

- At least 40 kg of magnetite was estimated to be transported into the boilers per year during steady full load operation (based on 7000 hours operation). However, the input rate of 40 kg/yr appears to be rather low. Pickering NGS has a significant amount of sludge in the steam generators (18 inch sludge pile on the tubesheet). The July 1980 survey results showed that a minimum of 4 kg magnetite was transported into the boilers. This means that a single startup can increase the annual boiler sludge deposits by at least 10%.

A.2.3 Bruce NGS-A Unit 2 (1976 Survey)

Feedtrain Design and Water Chemistry Operating History:

Bruce A Unit 2 has a mixed alloy feedtrain and uses all volatile treatment water chemistry with morpholine as the pH control additive. The feedwater is maintained at pH 8.9-9.3/A-13/. This study was conducted during the first startup.

Objectives:

1) to estimate corrosion product transport to the steam generators during the first startup;

2) to establish corrosion product transport baseline data for water chemistry control; and

3) to identify major sources of corrosion products.

Operating Mode During Sampling:

During the first startup, reactor power was increased in stages over a period of several months (August 1976 to February 1977). Samples were collected during the following power increases:

(i) zero to 0.1%
(ii) 0.1% to 3%
(iii) 3% to 10% (First synchronization)
(iv) 10% to 25%
(v) 25% to 50%
(vi) 63% to 88%

Result Summary:

a) Corrosion Product Transport During Startup

- Peaks in element concentration were clearly observed during load increases in each of the sampling points. The concentration increase appeared to correspond to the time when the system flow increased, see Fig. A.15 and A.16.

- The peak concentration values (eg., Fig. A.15, A.16) are orders of magnitude higher than those specified in the EPRI PWR Secondary Water Chemistry Guidelines/4/. A sample of the average corrosion product concentration during startup is shown in Table A.2.4.

- Iron and copper in transport originated from the condenser; zinc came from the condenser and LP heater, and nickel from the HP heater.

- Some deposition of iron and copper in the HP heaters was observed.

- Blowdown removed less than 10% of the corrosion products transported into the steam generators.

- During this first startup, as much as 2.2 kg/h of iron and 0.11 kg/h of copper were estimated to be transported into the steam generators.

b) Corrosion Product Transport During "Steady State" Operation

From February 8 to February 10, 1977 reactor power was slowly raised from 63% to 88% at 4 MW per hour. The corrosion product average concentrations in the feedtrain during that period are shown in Table A.2.5.

- The total iron concentration in feedwater was about 10 ppb during "steady state" operation, which is within the recommended limit by the steam generator manufacturer. However, the copper concentration in feedwater of 5 ppb was higher than the recommended 2 ppb limit.

- Most of the iron entering the steam generators originated in the hotwell, upstream of the condensate extraction pump.

- Copper concentration increased at each sampling point throughout the secondary system. Therefore the condenser, LP heaters and the HP heaters all contributed to the copper in transport.

- The Monel HP heaters were the primary source for nickel ingress to the steam generators.

- Relatively high zinc levels observed throughout the feedwater system were likely due to corrosion of the condenser.

- Boiler blowdown was not effective in removing corrosion products from the steam generators.

- 200 kg/yr of iron was estimated to be transported into the steam generators, assuming 6000 hours of operation per year.

A.2.4 Bruce NGS-A Unit 2 (1980 Survey)

Objective:

1) to determine the corrosion product ingress to pre-heater and steam generators during steady load operation.

A modified integrated sampling technique was used in this survey. 10 L of feedwater were filtered at a flow rate of 400 mL/min. Only the weight of the suspended solids was recorded. The elemental composition was not analyzed/A-14/.

Result Summary:

- The average particulate corrosion product concentration and transport rate in the steam plant STPA condensate (not from the turbines) return were 5 ppb and 0.05 kg/day, respectively.
- Blowdown was not an effective method to remove corrosion products from the steam generators. At 1.5 L/s blowdown the removal efficiency of suspended solids was 0.2%; at 3.0 L/s, the efficiency was 5% (see Table A.2.5). By doubling the blowdown flowrate, the removal efficiency appeared to increase 25 times (from 0.2% to 5%). The reason was not clear at this point, although some corrosion products might be sloughed off from the blowdown pipe due to the faster flow.
- Significant corrosion product deposition across the preheater was observed (see Table A.2.6). The pre-heater is not an integral part of the steam generator and has no blowdown.
- The average particulate concentration at the preheater outlet during steady operation was 6.4 ppb.

A.3 Survey of a Japanese Utility

Feedtrain Design and Water Chemistry Operating History:

No details of the power plant design were given in the report/A-15/. However, some information on the construction materials of the secondary system was given in the panel discussion section. For example, the condenser tubes and the low pressure feedwater heater tubes are made of aluminum brass; the high pressure heaters are tubed with cupronickel. The steam generators are equipped with Inconel 600 tubes and the moisture separator contains cupronickel. A schematic diagram of the secondary system is shown in Figure A.17. The feedtrain has a deaerator and uses AVT ammonia water chemistry.

Objective:

1) to establish an optimum pH value in feedwater by monitoring corrosion product transport to steam generators.

2) to establish an optimum hydrazine injection rate (by correlating hydrazine concentration to corrosion product level in feedwater).

3) to evaluate the performance of the condensate polisher.

Result Summary:

- The element concentration at steady load operation is shown in Figure A.17. With pH at 9.2, the total corrosion product concentrations in the final feedwater were: iron, 13.0 ppb; nickel, 0.6 ppb; and copper, below 0.2 ppb.

- The optimum pH (9.2) was established by monitoring the iron, copper and nickel transports in the feedwater and the moisture separator drains at various pH's. Iron and nickel concentration in the feedwater decreased as feedwater conductivity (ie, pH) increased. On the other hand, copper concentration in the feedwater started to increase above 4.5 μS/cm (25°C), which corresponds to a pH value of 9.2 approximately.

- To maintain feedwater pH at 9.2 ammonia injection rate was adjusted to give a conductivity of 4 μS/cm (25°C) at the deaerator inlet. Hydrazine was maintained at 0.2 ppm at the deaerator inlet.

- The condensate polisher was effective in removing corrosion products in the feedwater, eg. concentration of iron and copper in influent: 9 ppb and 1 ppb respectively; concentrations in effluent: 3 ppb and 0.2 ppb respectively.

- The nickel in transport came from the high pressure heaters.

- An important source of iron was the moisture separator drains. The feedwater iron concentration increased from 5 ppb to 13 ppb, with the input from the moisture separator drains. The increase was much larger than expected. Normally, the flow in the moisture separator drains is only a very small fraction of the feedwater flow. The iron concentration in the moisture separator drains was 28 ppb, in order to increase the feedwater iron concentration from

5 ppb to 13 ppb, the flow in the moisture separator drains would have to be about half of that of the feedwater, which was very high.

A.4 Survey of a Swiss Utility

A.4.1 Beznau NGS-2

Feedtrain Design and Water Chemistry Operating History:

Beznau-2 has a mixed alloy feedtrain/A-16/. The plant is equipped with a brass-tubed condenser and LP heaters, and has a deaerator (see Fig. A.18). Between 1974 and 1983 some system component material changes were made. The carbon steel part of some system components was replaced or cladded by stainless steel, eg., extraction pipes A3 and A4, the moisture separator shell and internals, cross-over pipe between the HP turbine and the moisture separator, and the shell of the horizontal LP feedwater heaters.

Beznau-2 uses AVT ammonia water chemistry in the secondary system. In 1974, cyclohexylamine (CHA) was used in addition to the normal hydrazine/ammonia treatment (ammonia approximately 0.7 mg/kg). In the 1983 survey, the use of CHA was suspended.

Objective:

1) to measure corrosion product concentrations and transport rates to establish a database.

2) to correlate corrosion product concentration changes to secondary system material changes.

Result Summary:

Iron and copper concentrations in the secondary system are shown in Table A.4.1, and iron transport rates are delineated in Figure A.19.

- The material changes reduced the release of iron eg, from 10.5 ppb to 4.1 ppb in the feedwater and from 104 ppb to 18 ppb in the moisture separator drains.

- Iron ingress to steam generators was reduced to 1170 μg/s, almost 1/5 of the 1974 value (5090 μg/sec). Reduction of iron in other streams was also substantial (see Fig. A.19).

- Copper pickup from the condenser, LP heaters, and the moisture separator drains appeared to be very low. However, an inspection of the steam side of the brass tubes in the LP heaters showed that a considerable amount of corrosion products was deposited on the unattacked part just below the zones of corrosion. Therefore, survey results need to be confirmed by inspection.

- Within the concentration range used (0.13 to 3.6 ppb), cyclohexylamine reduced iron transport in the feedwater and moisture separator drains as its concentration increased. Its effect on copper was considerably less.

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TABLE A.1.1

DESIGN CHARACTERISTICS OF 10 STUDY PLANTS BELONGING TO STEAM GENERATOR OWNERS GROUP (SGOG)

	Calvert Cliffs 1	Ginna	Prairie Island 1 2	Surry 2	Trojan	Turkey Point 4	ANO-1	Crystal River 3	Oconee 1
MWe (Net)	810	490	530	788	1090	693	846	825	860
Date of Commercial Operation	5/75	7/70	12/73 12/74	5/73	5/76	9/73	12/74	3/77	7/73
Steam Generators									
Design Type	Recirculating	Recirculating	Recirculating	Recirculating	Recirculating	Recirculating	Once-through	Once-through	Once through
Number	2	2	2	3	4	3	2	2	2
No.Tubes/Generator	8519	3260	3388	3388[a]	3388	3260	15531	15531	15531
m^2/Mld	24	17	18	18	18	18	29	30	29
Total Steam Flow, kg/min	87800	47300	53600	80000	113900	72500	84500	84100	83200
Condensate Treatment	PRF (since 12/76)	DB (since 1977)	PRF (Intermittent) [10/77-1/80]	DB (since 6/80)	PRF	None	DB	DB	PRF
No. Feedwater Heaters	6	5	5	6	7	6	6	6[b]	6
No. Feedwater Trains	3 low pressure 2 high pressure	2	2	2	2[c]	2	2	2[b]	2[d]
Tubing Materials									
Feedwater Heaters	Stainless	4Admiralty 1 80/20 CuNi	Stainless	4 Admiralty 1 90/10 CuNi 1 80/20 CuNi	4 Admiralty 3 90/10 CuNi	5 Admiralty 1 None	Stainless	Stainless[b]	4 Stainless 2 Carbon Steel
Condenser	70/30 CuNi	Admiralty[e]	Stainless	90/10 CuNi[f]	Arsenical Admiralty[g]	Aluminum Brass[h]	Admiralty	70/30 CuNi	Stainless
Reheaters	90/10 CuNi	90/10 CuNi	Carbon Steel	90/10 CuNi	90/10 CuNi	90/10 CuNi	90/10 CuNi	90/10 CuNi	Carbon Steel

a) Replacement steam generators have 3342 tubes per generator

b) Feedwater heater 4 is a single direct contact deaerating heater with carbon steel tank and dome.

c) In the condenser neck are 6 each feedwater heaters 1 and 2. They are connected in parallel strings: 3 strings for each feedwater train.

d) There are 3 parallel first point heaters, 2 each of later feedwater heaters.

e) Periphery and air removal section are tubed with stainless steel.

f) Replaced with titanium during 1980.

g) Air removal section is tubed with 70/30 CuNi.

h) Aluminum brass (90/10 CuNi air removal section) during NWT corrosion product studies (July 1975 - March 1976); condensers since have been retubed with titanium.

TABLE A.1.2

STEADY STATE IRON CONCENTRATIONS (ppb) AT DIFFERENT LOCATIONS IN THE FEEDTRAIN OF 10 SGOG PLANTS

Power Plant	Condensate Polishing [a]	Condenser Material[b]	Feedwater Heater Material [b]	Reheater Material	Condensate	Polished Condensate	High Pressure Drains	Moisture Separator Drains	Feedwater	Blowdown
Recirculating Steam Generator Systems										
Calvert Cliffs 1	None	70/30 CuNi	SS	90/10 CuNi	10.8	NA[c]	-	-	12.0	370
	PRF	70/30 CuNi	SS	90/10 CuNi	11.1	-	-	-	9.6	350
Ginna	DB	Admiralty	Copper Alloy	90/10 CuNi	15.0	2.2	-	-	-	-
Prairie Island 1	None				10.0	NA	17.0	-	11.0	320
	PRF	SS	SS	CS	5.2	0.2	-	-	-	-
Prairie Island 2	None				11.0	NA	6.8	23	13.0	1340
	PRF	SS	SS	CS	5.5	0.3	-	-	-	-
Surry 2	None	90/10 CuNi	Copper Alloy	90/10 CuNi	10.9	NA	10.5	-	11.0	250
Trojan	PRF	Admiralty	Copper Alloy	90/10 CuNi	10.5	0.1	13.0	-	4.0	-
Turkey Point 4	None	Alum. Brass	Copper Alloy	90/10 CuNi	13.4	NA	-	-	14.0	930
Once-through Steam Generator Systems										
ANO-1	DB	Admiralty	SS	90/10 CuNi	12.3	2.1	20.0	65	8.2	NA
Crystal River 3	DB	70/30 CuNi	SS	90/10 CuNi	13.3	3.7	5.7	-	10.0	NA
Oconee 1	PRF	SS	SS,CS	CS	5.3	0.4	8.0	37	4.5	NA

a) PRF = Powdered Resin Precoat Filters
DB = Deep Beds

b) SS = Stainless Steel
CS = Carbon Steel

c) NA = Not Applicable

TABLE A.1.3

STEADY STATE COPPER CONCENTRATIONS (ppb) AT DIFFERENT LOCATIONS IN THE FEEDTRAIN OF 10 SGOG PLANTS

Power Plant	Condensate Polishing [a]	Condenser Material [b]	Feedwater Heater Material [b]	Reheater Material	Condensate	Polished Condensate	High Pressure Drains	Moisture Separator Drains	Feedwater	Blowdown
Recirculating Steam Generator Systems										
Calvert Cliffs 1	None	70/30 CuNi	SS	90/10 CuNi	0.7	NA[c]	-	-	0.4	20
	PRF	70/30 CuNi	SS	90/10 CuNi	0.6	-	-	-	0.5	20
Ginna	DB	Admiralty	Copper Alloy	90/10 CuNi	0.8	0.08	-	-	-	-
Prairie Island 1	None									
	PRF	SS	SS	CS	NA	NA	NA	NA	NA	NA
Prairie Island 2	None									
	PRF	SS	SS	CS	NA	NA	NA	NA	NA	NA
Surry 2	None	90/10 CuNi	Copper Alloy	90/10 CuNi	1.6	NA	1.7	-	1.6	14
Trojan	PRF	Admiralty	Copper Alloy	90/10 CuNi	2.4	0.3	0.8	-	0.4	-
Turkey Point 4	None	Alum. Brass	Copper Alloy	90/10 CuNi	2.1	NA	-	-	1.4	28
Once-through Steam Generator Systems										
ANO-1	DB	Admiralty	SS	90/10 CuNi	2.9	0.3	0.3	0.7	0.3	NA
Crystal River 3	DB	70/30 CuNi	SS	90/10 CuNi	1.2	0.3	0.4	-	0.1	NA
Oconee 1	PRF	SS	SS,CS	CS	<0.15	<0.1	0.1	0.5	<0.1	NA

a) PRF = Powdered Resin Precoat Filters
DB = Deep Beds

b) SS = Stainless Steel
CS = Carbon Steel

c) NA = Not Applicable

TABLE A.1.4

STEADY STATE NICKEL CONCENTRATIONS (ppb) AT DIFFERENT LOCATIONS IN THE FEEDTRAIN OF 10 SGOG PLANTS

Power Plant	Condensate Polishing [a]	Condenser Material [b]	Feedwater Heater Material [b]	Reheater Material	Condensate	Polished Condensate	High Pressure Drains	Moisture Separator Drains	Feedwater	Blowdown
Recirculating Steam Generator Systems										
Calvert Cliffs 1	None	70/30 CuNi	SS	90/10 CuNi	0.5	NA[c]	-	-	0.4	10
	PRF	70/30 CuNi	SS	90/10 CuNi	0.4	-	-	-	0.3	15
Ginna	DB	Admiralty	Copper Alloy	90/10 CuNi	-	-	-	-	-	-
Prairie Island 1	None				0.02	NA	0.17	-	0.1	7
	PRF	SS	SS	CS	-	-	-	-	-	-
Prairie Island 2	None				0.09	NA	0.15	0.5	0.3	16
	PRF	SS	SS	CS	-	-	-	-	-	-
Surry 2	None	90/10 CuNi	Copper Alloy	90/10 CuNi	0.2	NA	0.5	-	0.4	11
Trojan	PRF	Admiralty	Copper Alloy	90/10 CuNi	-	-	-	-	0.2	-
Turkey Point 4	None	Alum. Brass	Copper Alloy	90/10 CuNi	0.2	NA	-	-	1.5	60
Once-through Steam Generator Systems										
ANO-1	DB	Admiralty	SS	90/10 CuNi	0.2	0.03	0.6	0.9	0.6	NA
Crystal River 3	DB	70/30 CuNi	SS	90/10 CuNi	0.6	0.07	0.4	-	0.5	NA
Oconee 1	PRF	SS	SS,CS	CS	<0.07	<0.07	0.2	0.6	0.2	NA

a) PRF = Powdered Resin Precoat Filters
DB = Deep Beds

b) SS = Stainless Steel
CS = Carbon Steel

c) NA = Not Applicable

TABLE A.1.5

OVERALL AVERAGE IRON CONCENTRATIONS (ppb) AT DIFFERENT LOCATIONS IN THE FEEDTRAIN OF 10 SGOG PLANTS

Power Plant	Condensate Polishing [a]	Condenser Material [b]	Feedwater Heater Material [b]	Reheater Material	Condensate	Polished Condensate	High Pressure Drains	Moisture Separator Drains	Feedwater	Blowdown
Recirculating Steam Generator Systems										
Calvert Cliffs 1	None	70/30 CuNi	SS	90/10 CuNi	11.6	NA[c]	-	-	17.0	370
	PRF	70/30 CuNi	SS	90/10 CuNi	17.6	-	-	-	10.0	350
Ginna	DB	Admiralty	Copper Alloy	90/10 CuNi	18.3	2.7	-	-	-	-
Prairie Island 1	None				12.6	NA	17.0	-	13.0	750
	PRF	SS	SS	CS	6.4	0.2	-	-	-	-
Prairie Island 2	None				19.8	NA	7.0	24	17.0	1520
	PRF	SS	SS	CS	7.6	0.3	-	-	-	-
Surry 2	None	90/10 CuNi	Copper Alloy	90/10 CuNi	17.9	NA	14.0	-	17.0	290
Trojan	PRF	Admiralty	Copper Alloy	90/10 CuNi	10.9	0.2	13.0	-	4.0	-
Turkey Point 4	None	Alum. Brass	Copper Alloy	90/10 CuNi	19.2	NA	-	-	19.0	1400
Once-through Steam Generator Systems										
ANO-1	DB	Admiralty	SS	90/10 CuNi	12.3	2.5	21.0	72	9.0	NA
Crystal River 3	DB	70/30 CuNi	SS	90/10 CuNi	14.5	5.5	5.7	-	11.0	NA
Oconee 1	PRF	SS	SS,CS	CS	6.7	0.9	9.1	48	5.0	NA

a) PRF = Powdered Resin Precoat Filters
DB = Deep Beds

b) SS = Stainless Steel
CS = Carbon Steel

c) NA = Not Applicable

TABLE A.1.6

OVERALL AVERAGE COPPER CONCENTRATIONS (ppb) AT DIFFERENT LOCATIONS IN THE FEEDTRAIN OF 10 SGOG PLANTS

Power Plant	Condensate Polishing [a]	Condenser Material [b]	Feedwater Heater Material [b]	Reheater Material	Condensate	Polished Condensate	High Pressure Drains	Moisture Separator Drains	Feedwater	Blowdown
Recirculating Steam Generator Systems										
Calvert Cliffs 1	None	70/30 CuNi	SS	90/10 CuNi	0.8	NA[c]	-	-	0.7	20
	PRF	70/30 CuNi	SS	90/10 CuNi	0.8	-	-	-	0.8	20
Ginna	DB	Admiralty	Copper Alloy	90/10 CuNi	1.9	0.14	-		-	-
Prairie Island 1	None									
	PRF	SS	SS	CS	NA	NA	NA	NA	NA	NA
Prairie Island 2	None									
	PRF	SS	SS	CS	NA	NA	NA	NA	NA	NA
Surry 2	None	90/10 CuNi	Copper Alloy	90/10 CuNi	2.6	NA	3.5	-	2.9	40
Trojan	PRF	Admiralty	Copper Alloy	90/10 CuNi	2.4	0.34	1.2	-	0.4	-
Turkey Point 4	None	Alum. Brass	Copper Alloy	90/10 CuNi	3.2	NA	-	-	2.6	50
Once-through Steam Generator Systems										
ANO-1	DB	Admiralty	SS	90/10 CuNi	3.7	0.55	0.33	1.4	0.4	NA
Crystal River 3	DB	70/30 CuNi	SS	90/10 CuNi	1.5	0.35	0.8	-	0.13	NA
Oconee 1	PRF	SS	SS,CS	CS	<0.15	<0.1	0.1	0.5	<0.1	NA

a) PRF = Powdered Resin Precoat Filters
DB = Deep Beds

b) SS = Stainless Steel
CS = Carbon Steel

c) NA = Not Applicable

TABLE A.1.7

OVERALL AVERAGE NICKEL CONCENTRATIONS (ppb) AT DIFFERENT LOCATIONS IN THE FEEDTRAIN OF 10 SGOG PLANTS

Power Plant	Condensate Polishing[a]	Condenser Material[b]	Feedwater Heater Material[b]	Reheater Material	Condensate	Polished Condensate	High Pressure Drains	Moisture Separator Drains	Feedwater	Blowdown
Recirculating Steam Generator Systems										
Calvert Cliffs 1	None	70/30 CuNi	SS	90/10 CuNi	0.6	NA[c]	-	-	0.6	10
	PRF	70/30 CuNi	SS	90/10 CuNi	0.8	-	-	-	0.3	15
Ginna	DB	Admiralty	Copper Alloy	90/10 CuNi	-	-	-	-	-	-
Prairie Island 1	None				0.03	NA	0.20	-	0.13	8
	PRF	SS	SS	CS	-	-	-	-	-	
Prairie Island 2	None				0.09	NA	0.17	0.5	0.3	16
	PRF	SS	SS	CS		-	-	-	-	-
Surry 2	None	90/10 CuNi	Copper Alloy	90/10 CuNi	0.2	NA	0.8	-	0.6	17
Trojan	PRF	Admiralty	Copper Alloy	90/10 CuNi	-	-	-	-	0.25	-
Turkey Point 4	None	Alum. Brass	Copper Alloy	90/10 CuNi	0.3	NA	-	-	2.0	90
Once-through Steam Generator Systems										
ANO-1	DB	Admiralty	SS	90/10 CuNi	0.2	0.07	0.7	1.0	0.6	NA
Crystal River 3	DB	70/30 CuNi	SS	90/10 CuNi	0.7	0.11	0.4	-	0.5	NA
Oconee 1	PRF	SS	SS,CS	CS	<0.07	<0.07	0.2	0.6	0.2	NA

a) PRF = Powdered Resin Precoat Filters
DB = Deep Beds

b) SS = Stainless Steel
CS = Carbon Steel

c) NA = Not Applicable

TABLE A.1.8

STEADY STATE IRON TRANSPORT (grams/h) AT DIFFERENT LOCATIONS IN THE FEEDTRAIN OF 10 SGOG PLANTS

Power Plant	Condensate Polishing [a]	Condenser Material [b]	Feedwater Heater Material [b]	Reheater Material	Condensate	Polished Condensate	High Pressure Drains	Moisture Separator Drains	Feedwater	Blowdown	Blowdown Efficiency %
Recirculating Steam Generator Systems											
Calvert Cliffs 1	None	70/30 CuNi	SS	90/10 CuNi	38	NA[c]	-	-	61	7.5	12.3
	PRF	70/30 CuNi	SS	90/10 CuNi	39	-	-	-	48	7.1	14.8
Ginna	DB	Admiralty	Copper Alloy	90/10 CuNi	32	4.6	-	-	-	-	-
Prairie Island 1	None				22	NA	16.0	-	36	4.4	12.2
	PRF	SS	SS	CS	12	0.5	-	-	-	-	-
Prairie Island 2	None				24	NA	6.5	5.9	40	18.2	45.5
	PRF	SS	SS	CS	12	0.6	-	-	-	-	-
Surry 2	None	90/10 CuNi	Copper Alloy	90/10 CuNi	34	NA	14.0	-	52	5.9	14.8
Trojan	PRF	Admiralty	Copper Alloy	90/10 CuNi	50	0.5	28.0	-	27	-	-
Turkey Point 4	None	Alum. Brass	Copper Alloy	90/10 CuNi	42	NA	-	-	64	16.4	25.6
Once-through Steam Generator Systems											
ANO-1	DB	Admiralty	SS	90/10 CuNi	43	7.4	28.0	16.0	40.0	NA	-
Crystal River 3	DB	70/30 CuNi	SS	90/10 CuNi	46	12.8	6.5	-	48.0	NA	-
Oconee 1	PRF	SS	SS,CS	CS	16	1.2	9.1	10.4	23.0	NA	-

a) PRF = Powdered Resin Precoat Filters
DB = Deep Beds

b) SS = Stainless Steel
CS = Carbon Steel

c) NA = Not Applicable

TABLE A.1.9

STEADY STATE COPPER TRANSPORT (grams/h) AT DIFFERENT LOCATIONS IN THE FEEDTRAIN OF 10 SGOG PLANTS

Power Plant	Condensate Polishing [a]	Condenser Material[b]	Feedwater Heater Material[b]	Reheater Material	Condensate	Polished Condensate	High Pressure Drains	Moisture Separator Drains	Feedwater	Blowdown	Blowdown Efficiency %
Recirculating Steam Generator Systems											
Calvert Cliffs 1	None	70/30 CuNi	SS	90/10 CuNi	2.5	NA[c]	-	-	2.0	0.4	20.0
	PRF	70/30 CuNi	SS	90/10 CuNi	2.1	-	-	-	2.4	0.4	16.7
Ginna	DB	Admiralty	Copper Alloy	90/10 CuNi	1.8	0.2	-	-	-	-	-
Prairie Island 1	None										
	PRF	SS	SS	CS	NA	NA	NA	NA	NA	NA	-
Prairie Island 2	None										
	PRF	SS	SS	CS	NA	NA	NA	NA	NA	NA	-
Surry 2	None	90/10 CuNi	Copper Alloy	90/10 CuNi	4.9	NA	2.2	-	7.9	0.3	3.8
Trojan	PRF	Admiralty	Copper Alloy	90/10 CuNi	11.4	1.5	1.7	-	2.4	-	-
Turkey Point 4	None	Alum. Brass	Copper Alloy	90/10 CuNi	6.7	NA	-	-	6.2	0.5	8.1
Once-through Steam Generator Systems											
ANO-1	DB	Admiralty	SS	90/10 CuNi	10.3	1.2	0.4	0.17	1.45	NA	-
Crystal River 3	DB	70/30 CuNi	SS	90/10 CuNi	4.3	0.9	0.4	-	0.45	NA	-
Oconee 1	PRF	SS	SS,CS	CS	<0.4	<0.1	0.15	0.13	<0.3	NA	-

a) PRF = Powdered Resin Precoat Filters
DB = Deep Beds

b) SS = Stainless Steel
CS = Carbon Steel

c) NA = Not Applicable

TABLE A.1.10

STEADY STATE NICKEL TRANSPORT (grams/h) AT DIFFERENT LOCATIONS IN THE FEEDTRAIN OF 10 SGOG PLANTS

Power Plant	Condensate Polishing [a]	Condenser Material [b]	Feedwater Heater Material [b]	Reheater Material	Condensate	Polished Condensate	High Pressure Drains	Moisture Separator Drains	Feedwater	Blowdown	Blowdown Efficiency %
Recirculating Steam Generator Systems											
Calvert Cliffs 1	None	70/30 CuNi	SS	90/10 CuNi	1.9	NA[c]	-	-	2.0	0.2	10.0
	PRF	70/30 CuNi	SS	90/10 CuNi	1.3	-	-	-	1.4	0.3	21.4
Ginna	DB	Admiralty	Copper Alloy	90/10 CuNi	-	-	-	-	-	-	-
Prairie Island 1	None	SS	SS	CS	0.04	NA	0.16	-	0.33	0.1	30.3
	PRF				-	-	-	-	-	-	-
Prairie Island 2	None	SS	SS	CS	0.20	NA	0.14	0.13	1.0	0.2	20.0
	PRF				-	-	-	-	-	-	-
Surry 2	None	90/10 CuNi	Copper Alloy	90/10 CuNi	0.54	NA	0.7	-	1.8	0.3]	16.7
Trojan	PRF	Admiralty	Copper Alloy	90/10 CuNi	-	-	-	-	1.4	-	-
Turkey Point 4	None	Alum. Brass	Copper Alloy	90/10 CuNi	0.61	NA	-	-	7.0	1.1	16.7
Once-through Steam Generator Systems											
ANO-1	DB	Admiralty	SS	90/10 CuNi	0.74	0.12	0.8	0.23	3.0	NA	-
Crystal River 3	DB	70/30 CuNi	SS	90/10 CuNi	2.2	0.25	0.4	-	2.1	NA	-
Oconee 1	PRF	SS	SS,CS	CS	<0.2	<0.2	0.2	0.17	1.2	NA	-

a) PRF = Powdered Resin Precoat Filters
DB = Deep Beds

b) SS = Stainless Steel
CS = Carbon Steel

c) NA = Not Applicable

TABLE A.1.11

OVERALL IRON TRANSPORT (grams/h) AT DIFFERENT LOCATIONS IN THE FEEDTRAIN OF 10 SGOG PLANTS

Power Plant	Condensate Polishing [a]	Condenser Material[b]	Feedwater Heater Material [b]	Reheater Material	Condensate	Polished Condensate	High Pressure Drains	Moisture Separator Drains	Feedwater	Blowdown	Blowdown Efficiency %
Recirculating Steam Generator Systems											
Calvert Cliffs 1	None	70/30 CuNi	SS	90/10 CuNi	41	NA[c]	-	-	84	7.5	9.0
	PRF	70/30 CuNi	SS	90/10 CuNi	62	-	-	-	50	7.0	14.0
Ginna	DB	Admiralty	Copper Alloy	90/10 CuNi	39	5.8	-	-	-	-	-
Prairie Island 1	None				28	NA	16	-	42	10.2	24.3
	PRF	SS	SS	CS	14.3	0.5	-	-	-	-	-
Prairie Island 2	None				44	NA	6.7	6.2	55	20.8	37.8
	PRF	SS	SS	CS	16.9	0.6	-	-	-	-	-
Surry 2	None	90/10 CuNi	Copper Alloy	90/10 CuNi	56	NA	18	-	69	7.0	10.1
Trojan	PRF	Admiralty	Copper Alloy	90/10 CuNi	52	1.0	28	-	27	-	-
Turkey Point 4	None	Alum. Brass	Copper Alloy	90/10 CuNi	60	NA	-	-	85	25	29.4
Once-through Steam Generator Systems											
ANO-1	DB	Admiralty	SS	90/10 CuNi	43	8.7	28	12.5	44	NA	-
Crystal River 3	DB	70/30 CuNi	SS	90/10 CuNi	50	18	6.5	-	51	NA	-
Oconee 1	PRF	SS	SS,CS	CS	20	2.7	10.4	13.5	25	NA	-

a) PRF = Powdered Resin Precoat Filters
DB = Deep Beds

b) SS = Stainless Steel
CS = Carbon Steel

c) NA = Not Applicable

TABLE A.1.12

OVERALL COPPER TRANSPORT (grams/h) AT DIFFERENT LOCATIONS IN THE FEEDTRAIN OF 10 SGOG PLANTS

Power Plant	Condensate Polishing [a]	Condenser Material [b]	Feedwater Heater Material [b]	Reheater Material	Condensate	Polished Condensate	High Pressure Drains	Moisture Separator Drains	Feedwater	Blowdown	Blowdown Efficiency %
Recirculating Steam Generator Systems											
Calvert Cliffs 1	None	70/30 CuNi	SS	90/10 CuNi	2.9	NA[c]	-	-	3.5	0.4	11.4
	PRF	70/30 CuNi	SS	90/10 CuNi	2.9	-	-	-	3.9	0.4	10.3
Ginna	DB	Admiralty	Copper Alloy	90/10 CuNi	4.1	0.3	-	-	-	-	-
Prairie Island 1	None							-			
	PRF	SS	SS	CS	NA	NA	NA	NA	NA	NA	-
Prairie Island 2	None										
	PRF	SS	SS	CS	NA	NA	NA	NA	NA	NA	-
Surry 2	None	90/10 CuNi	Copper Alloy	90/10 CuNi	8	NA	4.6	-	14	0.9	6.4
Trojan	PRF	Admiralty	Copper Alloy	90/10 CuNi	11.5	1.6	2.6	-	3	-	-
Turkey Point 4	None	Alum. Brass	Copper Alloy	90/10 CuNi	10	NA	-	-	12	0.7	5.8
Once-through Steam Generator Systems											
ANO-1	DB	Admiralty	SS	90/10 CuNi	13.1	1.9	0.5	0.33	1.9	NA	-
Crystal River 3	DB	70/30 CuNi	SS	90/10 CuNi	5.1	1.2	1.0	-	0.62	NA	-
Oconee 1	PRF	SS	SS,CS	CS	<0.4	<0.1	0.15	0.13	<0.3	NA	-

a) PRF = Powdered Resin Precoat Filters
DB = Deep Beds

b) SS = Stainless Steel
CS = Carbon Steel

c) NA = Not Applicable

TABLE A.1.13

OVERALL NICKEL TRANSPORT (grams/h) AT DIFFERENT LOCATIONS IN THE FEEDTRAIN OF 10 SGOG PLANTS

Power Plant	Condensate Polishing [a]	Condenser Material [b]	Feedwater Heater Material [b]	Reheater Material	Condensate	Polished Condensate	High Pressure Drains	Moisture Separator Drains	Feedwater	Blowdown	Blowdown Efficiency %
Recirculating Steam Generator Systems											
Calvert Cliffs 1	None	70/30 CuNi	SS	90/10 CuNi	2.1	NA[c]	-	-	3.2	0.2	6.3
	PRF	70/30 CuNi	SS	90/10 CuNi	2.9	-	-	-	1.5	0.3	20.0
Ginna	DB	Admiralty	Copper Alloy	90/10 CuNi	-	-	-	-	-	-	-
Prairie Island 1	None				0.6	NA	0.19	-	0.4	0.1	25.0
	PRF	SS	SS	CS	-	-	-	-	-	-	-
Prairie Island 2	None				0.21	NA	0.16	0.13	1.0	0.2	20.0
	PRF	SS	SS	CS	-	-	-	-	-	-	-
Surry 2	None	90/10 CuNi	Copper Alloy	90/10 CuNi	0.7	NA	1.2	-	3.0	0.4	13.3
Trojan	PRF	Admiralty	Copper Alloy	90/10 CuNi	-	-	-	-	1.7	-	-
Turkey Point 4	None	Alum. Brass	Copper Alloy	90/10 CuNi	1.0	NA	-	-	9.0	1.2	13.3
Once-through Steam Generator Systems											
ANO-1	DB	Admiralty	SS	90/10 CuNi	0.87	0.26	0.9	0.25	3.1	NA	-
Crystal River 3	DB	70/30 CuNi	SS	90/10 CuNi	2.4	0.37	0.45	-	2.2	NA	-
Oconee 1	PRF	SS	SS,CS	CS	<0.2	<0.2	0.2	0.17	1.2	NA	-

a) PRF = Powdered Resin Precoat Filters
DB = Deep Beds

b) SS = Stainless Steel
CS = Carbon Steel

c) NA = Not Applicable

TABLE A.1.14

CORROSION PRODUCT FORM (Percent Filterable) OF ELEMENTS IN SAMPLES COLLECTED IN FEEDTRAIN OF SGOG STUDY PLANTS

Plant/ Period	Condensate			Polished Condensate			High Pressure Drains			Feedwater			Blowdown		
	Iron	Copper	Nickel	Iron	Copper	Nickel	Iron	Copper	Nickel	Iron	Copper	Nickel	Iron	Copper	Nickel
Prairie Island 1															
Oct.-Dec. 1976	98	-	70	-	-	-	69	-	44	78	-	83	99	-	98
July 1977	98	-	47	-	-	-	-	-	-	89	-	62	99	-	98
Sept.-Nov. 1978	97	-	70	72	-	54	-	-	-	-	-	-	-	-	-
Prairie Island 2															
Aug.-Sept. 1976	98	-	69	-	-	-	53	-	50	84	-	83	-	-	-
Dec.1977-Feb.1978	96	-	66	72	-	39	-	-	-	-	-	-	-	-	-
Jan.-July 1979	95	-	63	66	-	-	-	-	-	-	-	-	-	-	-
Surry 2															
Oct.-Nov. 1975	98	87	80	-	-	-	39	92	-	77	96	63	99	98	99
Jan.-Feb. 1977	-	-	-	-	-	-	98	97	84	98	96	78	99.9	99.8	99.8
Trojan															
Jan. 1979	97	99	96	82	59	81	99	99	98	94	97	82	-	-	-
Feb.-Ap.l 1979	99	90	49	60	21	10	44	92	39	19	82	16	-	-	-
Turkey Point 4															
July-Sept. 1975	89	84	91	-	-	-	-	-	-	80	27	81	99.8	97	99.4
Ginna															
Jan.-June 1980	99	81	-	86	61	-	-	-	-	-	-	-	-	-	-

TABLE A.1.15

AVERAGE TOTAL CORROSION PRODUCT CONCENTRATIONS AT ST. LUCIE 1, APRIL TO AUGUST 1981

Location	Concentration, ppb			
	Iron	Nickel	Copper	Zinc
High Pressure Feedwater	8.5	0.21	0.13	1.2
Condensate Pump Discharge	7.4	0.05	0.17	0.12
3B Heater Outlet	7.1	0.15	0.43	0.96
High Pressure Heater Drain	14.0	0.19	0.23	0.07

TABLE A.1.16

AVERAGE CORROSION PRODUCT TRANSPORT RATES (g/h) AT ST. LUCIE 1, 1981

Location	Transportation Rate, g/h			
	Iron	Nickel	Copper	Zinc
High Pressure Feedwater	43.0	1.1	0.69	6.0
Condensate Pump Discharge	27.0	0.18	0.63	0.43
Low Pressure Feedwater Heater No. 3 Outlet	26.0	0.58	1.6	3.6
High Pressure Drain	22.0	0.30	0.30	0.12

TABLE A.1.17

AVERAGE STEADY STATE CORROSION PRODUCT CONCENTRATIONS AT MILLSTONE 2

Location	Concentration, ppb			
	Iron	Copper	Nickel	Zinc
Condensate Demineralizer Inlet	8.8	1.1	0.30	0.24
Condensate Demineralizer Outlet	1.5	0.19	0.06	0.11
Steam Generator 1 Blowdown	47.0	6.6	6.5	21.0
Steam Generator 2 Blowdown	32.0	4.0	4.5	18.0

TABLE A.1.18

AVERAGE STEADY STATE CORROSION PRODUCT TRANSPORT RATES AT MILLSTONE 2

Location	Transport Rate, g/h			
	Iron	Copper	Nickel	Zinc
Condensate Demineralizer Inlet	32.0	4.0	1.2	0.9
Condensate Demineralizer Outlet	8.6	0.73	0.24	0.45
Steam Generator Blowdown (1 and 2)	0.3	0.03	0.04	0.15

TABLE A.1.19

ANO-2 SECONDARY WATER CHEMISTRY SPECIFICATIONS WITH AND WITHOUT BORIC ACID

Parameter	Power Operation >5% to Full Power Without Boric Acid	Low Power Boric Acid Soak: Power 25%	Power Operation >5% to Full Power With Boric Acid
Steam Generator Blowdown	Normal Value	Normal Value	Normal Value
pH	8.5 - 9.2	6.0 - 6.8	7.2 - 7.8
Cation Cond., µS/cm	≤ 0.8	≤ 4.0	≤ 3.0
Sodium, ppb	≤ 20	≤100	≤ 20
Chloride, ppb	≤ 20	≤100	≤ 20
Silica, ppb	≤300	≤300	≤300
Sulfate, ppb	≤ 20	≤100	≤ 20
Boron, ppm	-	40 - 60	5 - 10
Main Feedwater			
pH	8.8 - 9.2	6.5 - 8.5	8.2 - 8.6
Cation Cond., µS/cm	≤ 0.2	≤ 0.5	≤ 0.5
Sodium, ppb	≤ 3	≤ 3	≤ 3
Dissolved O_2, ppb	≤ 3	≤ 3	≤ 3
Total Iron, ppb	≤20	≤20	≤20
Total Copper, ppb	≤ 2	≤ 2	≤ 2
Hydrazine, ppb	$\geq 3 \times [O_2]$	$\geq 3 \times [O_2]$	$\geq 3 \times [O_2]$
Ammonia	To be consistent with pH	To be consistent with pH and boron	To be consistent with pH and boron
Condensate			
Dissolved O_2, ppb	≤10	≤10	≤10

TABLE A.1.20

PERCENTAGE OF FILTERABLE CORROSION PRODUCTS IN SAMPLES FROM ANO-2

Sample Point	Average Fraction on 0.45 micron Filter, %		
	Iron	Copper	Nickel
Condensate	99	92	77
Low Pressure Heater 4 Effluent	68	96	40
Heater Drain Tank	60	95	34
High Pressure Heater 2 Inlet	62	98	26
Feedwater	67	97	50
Steam Generator Blowdown	95	98	99
Low Pressure Heater 7 Shell Drain	98	84	60
High Pressure Heater 2 Shell Drain	43	92	20

TABLE A.1.21

AVERAGE CORROSION PRODUCT CONCENTRATIONS (ppb) IN FEEDWATER OF INDIAN POINT 2 DURING 1977 SAMPLING STUDY

	Iron	Copper
Feedwater	11.1 (21 10)	19.5 (21 10)
Condensate	13.1 (21 10)	4.9 (21 10)
High Pressure Drains	10.0 (21 10)	15.4 (21 10)
Feedwater Heater 22A Outlet	16.0 (1050)	4.9 (1050)
Feedwater Heater 24A Outlet	16.0 (1050)	11.2 (1050)
Feedwater Heater 25A Outlet	12.9 (1050)	13.5 (1050)

Sampling Hours in Brackets

TABLE A.1.22

OXYGEN CONCENTRATIONS IN FEEDWATER OF INDIAN POINT 2 DURING STEADY POWER OPERATION IN SEPTEMBER 1977

Location	Oxygen Concentration ppb
Condensate (prior to hydrazine or Amerzine addition)	50 - 55
Outlet of Feedwater Heater 22A	27 - 32
Outlet of Feedwater Heater 23A	10 - 13
Outlet of Feedwater Heater 24A	5 - 7
Outlet of Feedwater Heater 25A	3 - 4
High Pressure Drain 21	3 - 4
Feedwater	<1

TABLE A.1.23
AVERAGE CORROSION PRODUCT CONCENTRATIONS AT FORT CALHOUN

	Iron, ppb				Copper, ppb			
	Filterable	Non-Filterable	Total	Filterable Fraction %	Filterable	Non-Filterable	Total	Filterable Fraction %
Condensate	8.84	0.22	9.1	97	0.18	0.02	0.20	90
Intermediate Feedwater	8.64	0.65	9.3	93	3.8	0.012	3.8	99
Heater Drain Pump	3.9	5.7	9.6	41	0.02	0.01	0.02	100
Final Feedwater	5.7	4.8	10.5	54	1.52	0.02	1.54	99
Blowdown (Total)	52.4	1.2	54.0	97	2.9	0.03	2.9	100
SG (A)	65.3	1.3	66.6	98	3.3	0.013	3.3	100
SG (B)	39.8	1.1	41.0	97	2.5	0.04	2.5	100

TABLE A.1.24

SUMMARY OF CORROSION PRODUCT CONCENTRATIONS AND MASS TRANSPORT AT FORT CALHOUN

	Average Concentration, ppb		Average Transport Rate, g/h	
	Iron	Copper	Iron	Copper
August 15 - September 27/85				
Condensate (CPD)	9.1	0.2	18.6	0.4
Intermediate Feedwater (IFW)	9.3	3.8	17.5	7.2
Heater Drain Pump (HDP)	9.6	0.02	7.1	0.02
Final Feedwater (FFW)	10.5	1.54	29.1	4.3
HDP + IFW	NA	NA	24.6	7.2
August 29 - September 27/85				
Blowdown	54	2.9	0.48	0.03
Final Feedwater	10.5	1.61	29.3	4.5

TABLE A.1.25

AVERAGE CORROSION PRODUCT CONCENTRATIONS AT PRAIRIE ISLAND 2

	Iron, ppb							
	Ammonia Control				Morpholine Control			
	F	NF	Total	Filterable Fraction %	F	NF	Total	Filterable Fraction %
Condensate	4.90	0.04	4.94	99	2.08	0.07	2.51	97
Intermediate Feedwater	9.28	0.06	9.34	99	2.93	0.04	2.97	99
Feedwater	5.45	1.94	7.39	74	2.2	1.1	3.3	67
Heater Drain Pump	4.55	2.56	7.11	64	2.57	1.35	3.92	66
Blowdown	392	2	394	99	48	3	51	94

F = Filterable
NF = Non-Filterable

TABLE A.1.26

AVERAGE CORROSION PRODUCT TRANSPORT RATES AT PRAIRIE ISLAND 2

	Iron, grams/h	
	Ammonia Control	Morpholine Control
Condensate	11.3	4.9
Intermediate Feedwater	21.2	6.8
Feedwater	23.5	10.3
Heater Drain Pump	6.5	3.5
Blowdown	13.6	1.9
Buildup in Steam Generators*	9.9	8.4

* Feedwater Input - Blowdown Removal

TABLE A.1.27
AVERAGE CORROSION PRODUCT CONCENTRATIONS AT BEAVER VALLEY
(April 14 - May 16, 1986)

	Iron, ppb				Copper, ppb			
	Filterable	Non-Filterable	Total	Filterable Fraction %	Filterable	Non-Filterable	Total	Filterable Fraction %
Condensate	1.35	0.04	1.39	97	0.022	0.008	0.03	73
Feedwater	5.4	1	6.4	84	0.02	0.01	0.03	67
Blowdown	24	3	27	89	0.58	0.01	0.59	98

TABLE A.1.28
AVERAGE CORROSION PRODUCT TRANSPORT RATES AT BEAVER VALLEY
(April 14 - May 16, 1986)

	Iron, grams/h	Copper, grams/h
Condensate	3.9	0.08
Feedwater	28	0.12
Blowdown	1.13	0.02
Buildup in Steam Generators*	27	0.1

*Feedwater Input—Blowdown Removal

TABLE A.2.1
IRON AND ZINC TRANSPORT DATA DURING STEADY STATE OPERATION AT POINT LEPREAU NGS
(Sampling Period, November 6-13, 1984)

Sample Number	Sample Location	Date	Time (Hours)	Volume (Liters)	** System Flowrate (kg/sec)	Total Iron (ppb)	Total Iron (grams/hr)	Filterable Iron (%)	Total Zinc (ppb)	Total Zinc (grams/hr)	Filterable Zinc (%)
1A	CEP	11/8-9/84	0652-0129	36.45	754.30	2.42	6.58	94.8	0.13	0.35	69.09
2A	LP HTR #3 Out*	11/8-9/84	1931-0135	93.15	754.30	-	-	-	-	-	-
3A	BFP Discharge	11/8-9/84	1930-0146	87.74	951.65	3.28	11.24	94.7	0.10	0.33	43.86
4A	HP HTR Out	11/8-9/84	1933-0149	97.10	951.65	2.87	9.84	87.4	0.17	0.50	34.74
5A	SG Blowdown #2	11/8/84	0733-1603	26.06	0.45	1842.43	2.97	100.0	16.73	0.02	91.74
6A	SG Blowdown #4	11/8/84	0745-1604	19.05	0.43	651.56	1.00	99.9	8.98	0.01	84.80
7A	Reheater Drains	11/8-9/84	0706-0139	51.00	82.64	1.08	0.32	69.6	1.61	0.48	12.46
8A	MSD	11/8-9/84	0619-0120	60.46	89.86	7.16	2.32	39.0	0.27	0.09	51.52
9A	HP HTR Drains***	11/8-9/84	0608-0113	114.50	202.53	6.26	4.56	23.5	4.77	3.48	8.47
1B	CEP	11/9-10/84	0134-0517	57.75	754.30	2.25	6.11	>99.1	0.09	0.24	70.00
2B	LP HTR #3 Out	11/9-10/84	0139-0528	100.95	754.30	5.54	15.04	99.5	0.42	1.13	28.57
3B	BFP Discharge	11/9-10/84	0149-0516	59.29	959.93	2.26	7.81	88.6	0.12	0.41	49.30
4B	HP HTR Out	11/9-10/84	0149-0527	123.10	959.93	2.67	9.21	84.6	0.08	0.28	67.16
5B	SG Blowdown #2	11/9/84	1301-1924	18.14	0.45	805.54	1.31	99.9	10.25	0.01	86.02
6B	SG Blowdown #4	11/9/84	1306-1929	16.30	0.37	644.93	0.87	99.9	10.37	0.01	84.62
7B	Reheater Drains	11/9-10/84	0143-0536	69.40	83.89	1.06	0.32	67.2	1.31	0.39	14.05
8B	MSD	11/9-10/84	0124-0555	105.54	87.01	6.31	1.98	40.5	1.21	0.38	29.41
9B	HP HTR Drains***	11/9-10/84	0118-0551	83.20	193.19	6.17	4.29	44.5	2.70	1.88	20.00
1C	CEP	11/10-11/84	0524-0110	43.80	754.30	2.24	6.07	94.5	0.10	0.27	81.40
2C	LP HTR #3 Out	11/10-11/84	0532-0114	42.45	754.30	26.11	70.90	99.2	0.93	2.52	73.06
3C	BFP Discharge	11/10-11/84	0521-0124	50.15	950.48	2.32	7.94	82.5	0.09	0.32	57.89
4C	HP HTR Out	11/10-11/84	0530-0127	57.88	950.48	2.85	9.76	82.6	0.10	0.34	65.22
5C	SG Blowdown #2	11/10-11/84	1648-0131	9.26	0.35	595.55	0.74	99.7	9.07	0.01	71.43
6C	SG Blowdown #4	11/10-11/84	1650-0135	13.65	0.32	638.37	0.74	99.8	10.55	0.01	83.33
7C	Reheater Drains	11/10-11/84	0540-0119	50.75	84.10	1.07	0.32	52.1	1.10	0.33	14.29
8C	MSD	11/10-11/84	0600-0053	49.98	91.38	7.43	2.44	48.8	0.29	0.10	60.14
9C	HP HTR Drains***	11/10-11/84	0557-0050	54.90	205.13	6.03	4.45	55.9	2.49	1.84	23.81
1D	CEP	11/11-12/84	0112-1024	81.60	754.30	1.79	4.87	>98.8	0.11	0.30	69.83
2D	LP HTR #3 Out	11/11-12/84	0118-1024	89.00****	754.30	11.54	31.33	99.2	0.60	1.62	42.40
3D	BFP Discharge	11/11-12/84	0127-1024	121.88	960.33	1.85	6.39	84.4	0.09	0.31	56.56
4D	HP HTR Out	11/11-12/84	0130-1024	75.22	960.33	2.88	9.96	83.7	0.10	0.36	61.29
5D	SG Blowdown #2	11/11/84	1142-2339	29.14	0.43	652.73	1.02	99.9	9.81	0.01	83.92
6D	SG Blowdown #4	11/11/84	1148-2338	37.75	0.38	625.71	0.84	99.9	7.89	0.01	92.28
7D	Reheater Drains	11/11-12/84	0121-1025	90.10	83.98	1.10	0.33	61.7	0.85	0.26	21.82
8D	MSD	11/11-12/84	0057-1165	109.26	89.63	7.12	2.30	49.8	0.25	0.08	62.50
9D	HP HTR Drains***	11/11-12/84	0054-1122	93.20	196.62	6.05	4.28	53.2	2.12	1.50	30.30

* Sample lost during analysis. No value to report.

** CEP flow rate obtained from turbine heat balance flow sheet. Other flow rates represent actual measurements.

*** HP heater drain sample taken from HP heater drain A only. It is assumed HP heater drain A and B will have similar concentrations. The flow rate values reflect total HP heater drain flow.

**** The volume throughput for the cation resin membrane for this sample was 87.35 liters.

TABLE A.2.2

IRON AND ZINC TRANSPORT DATA AT POINT LEPREAU NGS

(Sampling Period, May 1-18, 1985)

Sample* Number	Sample Location	Date	Time (Hours)	Volume (Liters)	System† Flowrate (kg/sec)	Total Iron (ppb)	Total Iron (grams/hr)	Percent Filterable Iron (%)	Total Zinc (ppb)	Total Zinc (grams/hr)	Percent Filterable Zinc (%)
1A	CEP	5/1-2/85	0900-0830	84.40	676.96	86.02	209.63	99.86	1.49	3.64	63.33
2A	LP HTR #3 Out	5/1-2/85	0900-0830	69.50	676.96	4.46	10.87	96.77	0.30	0.74	9.52
3A	BFP Discharge	5/1-2/85	0900-0830	82.60	986.96	25.97	92.27	97.90	0.40	1.42	72.73
4A	HP HTR Out	5/1-2/85	0900-0830	79.90	986.96	31.75	112.82	94.60	0.19	0.67	86.67
5A	SG Blowdown #2**	5/1-2/85	0900-0830	74.30	0.46	11978	19.87	-	62	0.10	-
6A	SG Blowdown #4**	5/1-2/85	0900-0830	39.10	0.48	36317	63.11	-	166	0.29	-
7A	Reheater Drains	5/1-2/85	0900-0830	69.80	51.06	4.48	0.82	72.40	0.58	0.11	45.00
8A	MSD	5/1-2/85	0900-1030	46.80	92.51	12.74	4.24	67.11	0.13	0.04	50.00
9A	HP HTR Drains	5/1-2/85	0940-1030	46.10	209.14	15.16	11.42	79.83	0.24	0.18	54.55
1B	CEP	5/2-3/85	1020-0815	54.40	680.45	10.22	25.04	89.93	0.11	0.27	33.33
2B	LP HTR #3 Out	5/2-3/85	1020-0815	94.70	690.45	1.19	2.92	82.30	0.30	0.72	3.57
3B	BFP Discharge	5/2-3/85	1020-0815	67.90	965.20	10.40	36.13	92.07	0.25	0.87	29.41
4B	HP HTR Out	5/2-3/85	1020-0815	70.30	965.20	11.27	39.15	86.87	0.13	0.44	55.56
5B	SG Blowdown #2**	5/2-3/85	1020-0815	45.50	0.48	23077	40.08	-	114	0.20	-
6B	SG Blowdown #4**	5/2-3/85	1020-0815	61.70	0.50	12642	22.74	-	78	0.14	-
7B	Reheater Drains	5/2-3/85	1020-0815	58.60	84.60	3.34	1.02	60.20	0.44	0.14	34.62
8B	MSD	5/2-3/85	1100-0945	82.90	90.00	9.72	3.15	51.24	0.17	0.05	21.43
9B	HP HTR Drains	5/2-3/85	1100-0945	80.80	203.75	8.33	6.11	61.37	0.16	0.12	38.46
1C	CEP	5/10/85	1550-2300	40.00	524.00	492.33	928.73	99.47	6.30	11.88	97.28
2C	LP HTR #3 Out	5/10/85	1550-2300	34.30	524.00	33.03	62.31	98.23	0.50	0.93	53.62
3C	BFP Discharge	5/10/85	1550-2300	29.40	767.00	177.72	490.72	99.52	1.19	3.29	94.29
4C	HP HTR Out	5/10/85	1550-2300	34.20	767.00	173.92	490.22	99.19	0.99	2.75	97.06
5C	SG Blowdown #2**	5/10/85	1550-2300	34.50	0.48	8852	15.38	-	75	0.13	-
6C	SG Blowdown #4**	5/10/85	1550-2300	77.40	0.50	8398	15.11	-	101	0.18	-
7C	Reheater Drains	5/10/85	1550-1854	9.50	84.60	6.63	2.02	44.44	0.53	0.16	40.00
8C	MSD	5/10/85	1550-2058	8.00	90.00	50.91	16.49	85.49	0.80	0.26	57.14
9C	HP HTR Drains	5/10/85	1550-2058	11.00	203.75	363.45	266.59	98.80	3.82	2.50	90.48
1D	CEP	5/17-10/85	1945-0820	31.40	362.00	271.94	354.40	99.54	4.71	6.14	94.59
2D	LP HTR #3 Out	5/17-10/85	1945-0820	39.30	362.00	29.13	37.97	95.02	0.79	1.03	70.97
3D	BFP Discharge	5/17-10/85	1945-0820	29.60	529.00	338.11	642.68	99.30	3.85	7.32	94.74
4D	HP HTR Out	5/17-10/85	1945-0820	49.80	528.00	261.75	497.53	99.73	2.51	4.77	98.40
5D	SG Blowdown #2**	5/17-10/85	1945-0820	16.40	0.53	53659	102.38	-	506	0.97	-
6D	SG Blowdown #4**	5/17-10/85	1945-0820	30.00	0.54	17857	34.71	-	198	0.39	-
7D	Reheater Drains	5/10/85	0750-1310	17.00	84.60	11.35	3.46	87.05	1.06	0.32	38.89
8D	MSD	5/10/85	0920-1310	12.90	90.00	139.77	45.28	77.37	4.57	1.48	23.73
9D	HP HTR Drains	5/10/85	0920-1310	16.80	203.75	73.51	53.92	97.17	0.77	0.57	61.54

** Filterable material was present on both the membrane filter and cation resin membrane on these samples. Therefore, the membranes were combined as one sample for analysis.

† Flowrates based on information provided by Point Lepreau personnel.

* System condition during sample collection
A = Reheater testing, minor flow variations in system
B = Steady load operation right after reheater testing
C = Shutdown
D = Startup

TABLE A.2.3
IRON TRANSPORT DATA AT POINT LEPREAU NGS
(January - April, 1986)

Test Phase	Sample Location	Date	Sample Flowrate (kg/sec)	Filterable* Iron (ppb)	Non-Filterable* Iron (ppb)	Total Iron (ppb)	Total Iron (grams/hr)	% Filterable Iron (%)
11/84	Low Pressure Heater #3 Outlet	11/8-12/84	754.3	14.3	0.1	14.4	39.1	99.3
	High Pressure Heater Outlet	11/8-12/84	951.6	2.3	0.4	2.7	9.3	85.2
	Reheater Drains	11/8-12/84	82.6	0.7	0.4	1.1	0.3	63.6
	Moisture Separator Drains	11/8-12/84	89.9	3.1	3.9	7.0	2.3	44.3
	High Pressure Heater Drains**	11/8-12/84	202.5	2.7	3.4	6.1	4.4	44.3
1	Low Pressure Heater #2 Outlet	1/1-30/86	754.3	3.0	0.5	3.5	9.5	85.7
	High Pressure Heater Outlet	1/1-30/86	951.6	5.3	3.0	8.3	28.4	63.8
	Reheater Drains	1/1-30/86	82.6	2.7	1.2	3.9	1.2	69.2
	Moisture Separator Drains	1/1-30/86	89.9	5.5	11.9	17.4	5.6	31.6
	High Pressure Heater Drains**	1/1-30/86	202.5	5.8	7.9	13.7	9.9	42.3
2	Low Pressure Heater #2 Outlet	1/30-2/24/86	754.3	20.0	0.6	20.6	55.9	97.1
	High Pressure Heater Outlet	1/30-2/24/86	951.6	6.2	4.3	10.5	35.9	59.1
	Reheater Drains	1/30-2/24/86	82.6	2.9	2.1	5.0	1.5	58.0
	Moisture Separator Drains	1/30-2/24/86	89.9	5.0	23.4	28.4	9.2	17.6
	High Pressure Heater Drains**	1/30-2/24/86	202.5	7.8	18.9	26.7	19.5	29.2
3	Low Pressure Heater #2 Outlet	2/24-3/26/86	754.3	15.0	1.0	16.0	43.4	93.7
	High Pressure Heater Outlet	2/24-3/26/86	951.6	4.5	2.9	7.4	25.4	60.8
	Reheater Drains	2/24-3/26/86	82.6	2.6	1.9	4.5	1.4	57.8
	Moisture Separator Drains	2/24-3/26/86	89.9	3.5	5.9	9.4	3.0	37.2
	High Pressure Heater Drains**	2/24-3/26/86	202.5	5.1	4.8	9.9	7.2	51.51
4	Low Pressure Heater #2 Outlet	3/26-4/18/86	754.3	15.0	2.0	17.0	46.1	88.2
	High Pressure Heater Outlet	3/26-4/18/86	951.6	6.0	1.7	7.7	26.4	77.9
	Reheater Drains	3/26-4/18/86	82.6	4.9	0.8	5.7	1.7	86.0
	Moisture Separator Drains	3/26-4/19/86	89.9	3.1	2.0	5.1	1.7	60.8
	High Pressure Heater Drains**	3/26-4/18/86	202.5	3.9	1.9	5.8	4.2	67.2

* Reported vales are averages of several (4 - 6) integrated samples collected during the indicated sample period.

** HP heater drain sample taken from HP heater drain A only. It is assumed HP heater drain A and B will have similar concentration. The flow rate values reflect total HP heater drain flow.

Test Phase	Water Chemistry Condition
1	Reduce residual concentration of hydrazine to 10 - 20 μg/kg, but maintain feedwater pH at 9.5 with ammonia addition.
2	Maintain residual hydrazine concventration at 10 - 20 μg/kg, but reduce feedwater pH to 9.2 using ammonia.
3	Maintain residual hydrazine concentration at 10 - 20 μg/kg, and feedwater pH at 9.2, but using morpholine addition.
4	Maintain residual hydrazine concentration at 10 - 20 μg/kg, and increase feedwater pH to 9.5 via morpholine addition.

TABLE A.2.4

Average Corrosion Product Concentration in Feedwater During First Startup at Bruce A-2 Reactor Power Increase From Zero to 0.1 Percent

Date (1976)	Sampling Point*	Element Concentration (µg/ml)			
		Fe	Cu	Ni	Zn
Aug 18	BFPD	0.74 ± 0.10	0.13 ± 0.01	0.01 ± <0.01	0.15 ± 0.01
	BFO	0.70 ± 0.04	0.16 ± 0.01	0.04 ± <0.01	0.17 ± 0.01
Aug 19	BFPD	0.47 ± 0.04	0.15 ± 0.01	<0.01 ± <0.01	0.15 ± 0.01
	BFO	0.52 ± 0.05	0.15 ± 0.01	0.10 ± 0.01	0.13 ± <0.01

* CEPD = condensate extraction pump discharge
BFPD = boiler feed pump discharge
BFO = HP heater outlet
BBD = boiler blowdown

TABLE A.2.5

Average Corrosion Product Concentration During Steady State Operation at Bruce A-2 Reactor Operating at 88% Full Power

Date (1977)	Sampling Point*	Element Concentration (µg/ml)			
		Fe	Cu	Ni	Zn
Feb 8	CEPD	0.014	0.007	0.003	0.008
	BFPD	0.015	0.011	0.004	0.006
	BFO	0.020	0.015	0.013	0.008
	BBD	0.15	0.032	0.015	0.13
Feb 9	CEPD	0.015	0.005	0.002	0.010
	BFPD	0.016	0.010	0.002	0.011
	BFO	0.014	0.011	0.005	0.009
	BBD	0.13	0.040	0.020	0.11
Feb 10	CEPD	0.013	0.005	0.002	0.006
	BFPD	0.010	0.007	0.004	0.010
	BFO	0.011	0.009	0.007	0.012
	BBD	0.14	0.019	0.010	0.12

TABLE A.2.6

CORROSION PRODUCT TRANSPORT AND BLOWDOWN EFFICIENCY AT BRUCE A

Sampling Location	Av. Particulate Concentration (ppb)	Av. Particulate Transport (kg/day)	Blowdown Efficiency (%)
Heater #5 Outlet (10)*	11.8	1.2	
Pre-heater Outlet (9)	6.4	0.65	
50% Blowdown (13)	13.2	0.002	0.2[+]
100% Blowdown (3)	36	0.009	5

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* Number of samples collected in parenthesis

[+] Average of 5 samples only

TABLE A.4.1

Corrosion Product Concentrations in the Steam Water Systems at Beznau 2

	Iron (ppb)			Copper (ppb)	
Sampling Point	1974 (CHA 0.13)*	1974 (CHA 3.6)	1983 (no CHA)	1974 (CHA 0.13)	1983 CHA 3.6
HP Heater	-	-	3.9	-	-
Moisture Separator Drain	158	104	18	0.6	0.4
Heater #2	-	-	16	-	-
Condensate	6.3	3.0	1.3	0.6	0.5
Final Feedwater	17.8	10.5	4.1	0.6	0.4

---

* Cyclohexylamine (CHA) concentration in ppm.

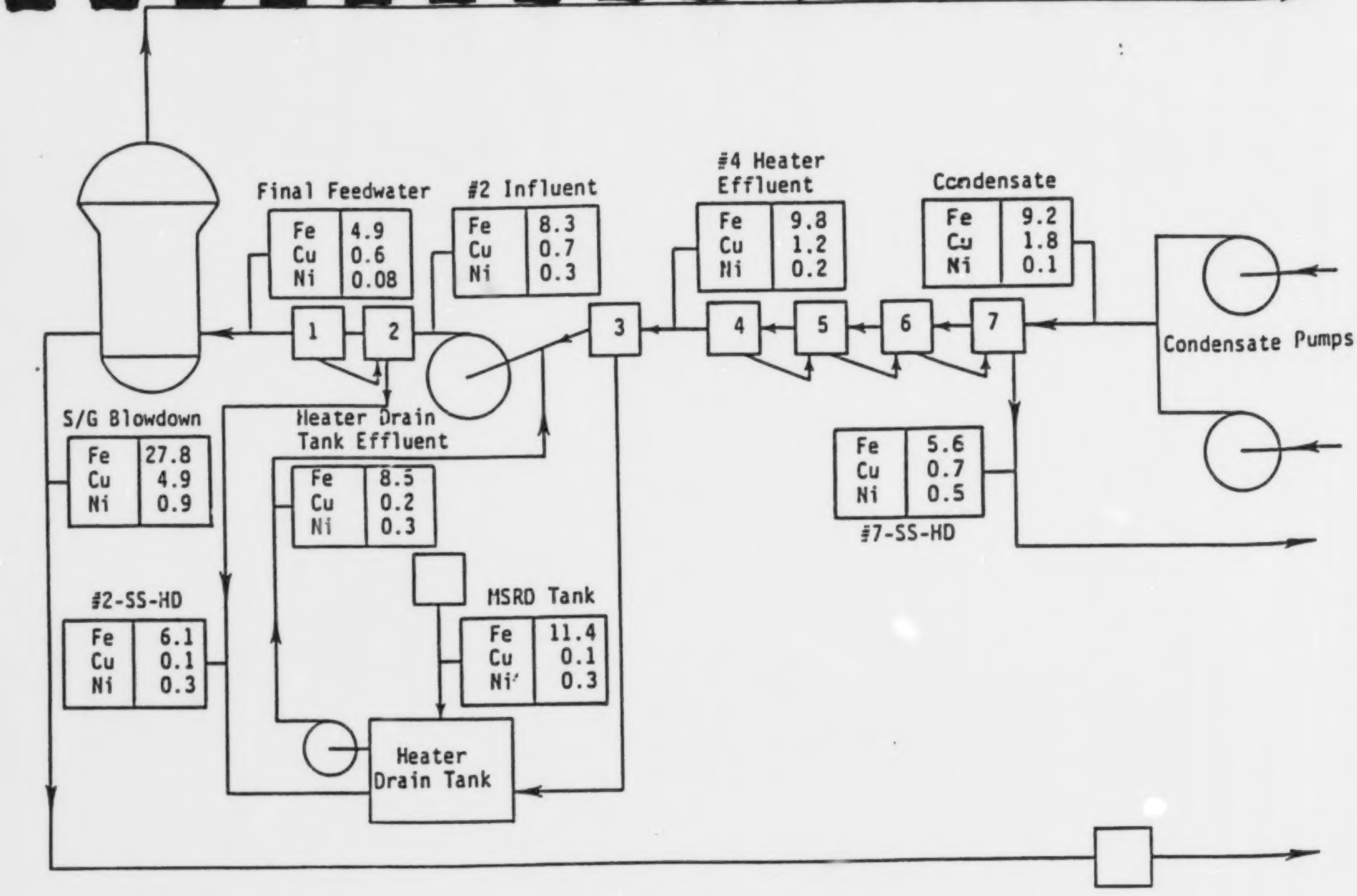

Final Feedwater
Fe 4.9
Cu 0.6
Ni 0.08
#2 Influent
Fe 8.3
Cu 0.7
Ni 0.3
#4 Heater Effluent
Fe 9.8
Cu 1.2
Ni 0.2
Condensate
Fe 9.2
Cu 1.8
Ni 0.1
1
2
3
4
5
6
7
Condensate Pumps
S/G Blowdown
Fe 27.8
Cu 4.9
Ni 0.9
Heater Drain Tank Effluent
Fe 8.5
Cu 0.2
Ni 0.3
Fe 5.6
Cu 0.7
Ni 0.5
#7-SS-HD
#2-SS-HD
Fe 6.1
Cu 0.1
Ni 0.3
MSRD Tank
Fe 11.4
Cu 0.1
Ni 0.3
Heater Drain Tank

FIGURE A.1
PRE-BORIC ACID TREATMENT AVERAGE CORROSION PRODUCT CONCENTRATIONS (ppb) IN FEEDTRAIN A OF ANO-2

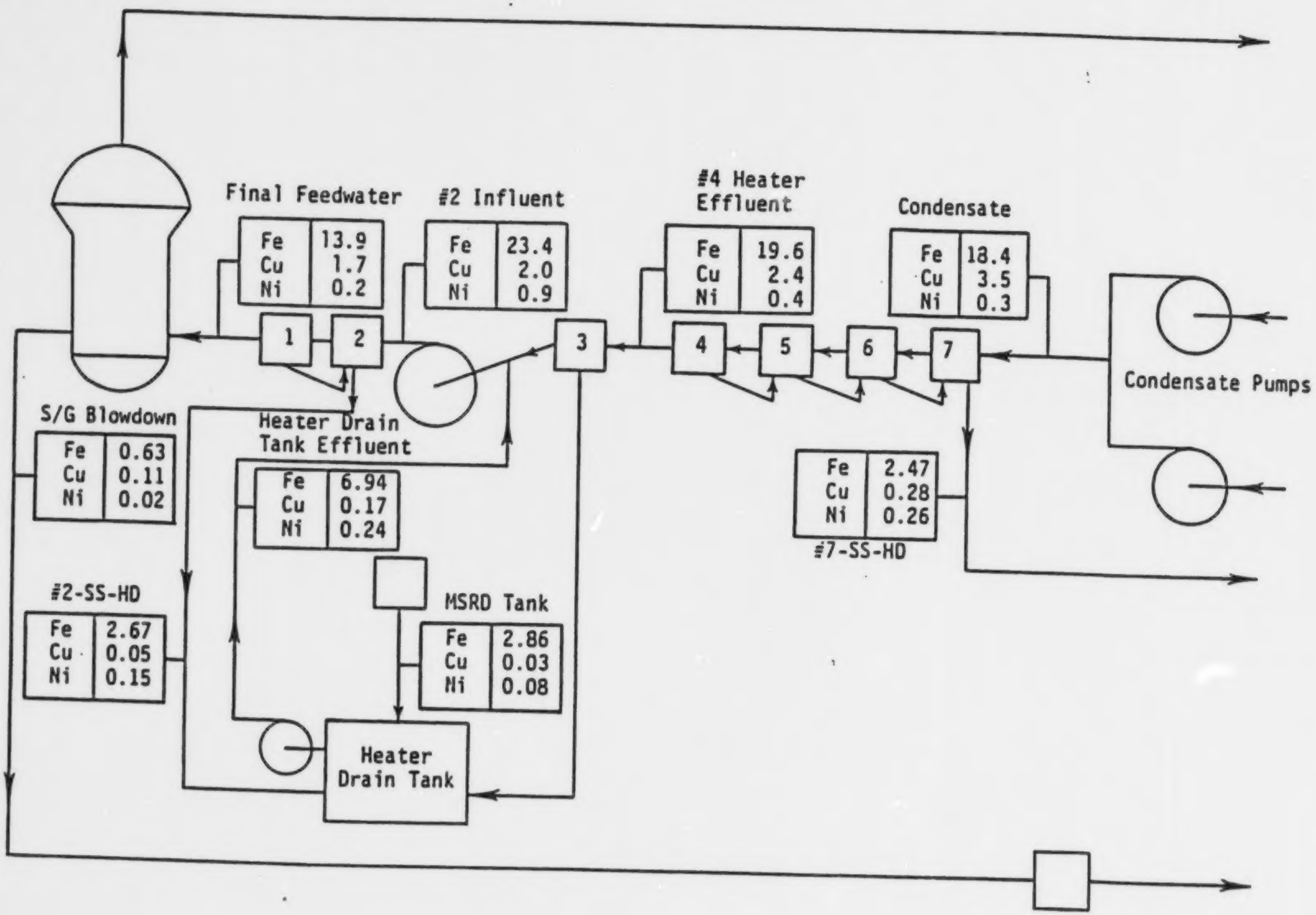

Final Feedwater
Fe 13.9
Cu 1.7
Ni 0.2
#2 Influent
Fe 23.4
Cu 2.0
Ni 0.9
#4 Heater Effluent
Fe 19.6
Cu 2.4
Ni 0.4
Condensate
Fe 18.4
Cu 3.5
Ni 0.3
1
2
3
4
5
6
7
Condensate Pumps
S/G Blowdown
Fe 0.63
Cu 0.11
Ni 0.02
Heater Drain Tank Effluent
Fe 6.94
Cu 0.17
Ni 0.24
#7-SS-HD
Fe 2.47
Cu 0.28
Ni 0.26
#2-SS-HD
Fe 2.67
Cu 0.05
Ni 0.15
MSRD Tank
Fe 2.86
Cu 0.03
Ni 0.08
Heater Drain Tank

FIGURE A.2
PRE-BORIC ACID TREATMENT AVERAGE CORROSION PRODUCT TRANSPORT RATES (g/h) IN FEEDTRAIN A OF ANO-2

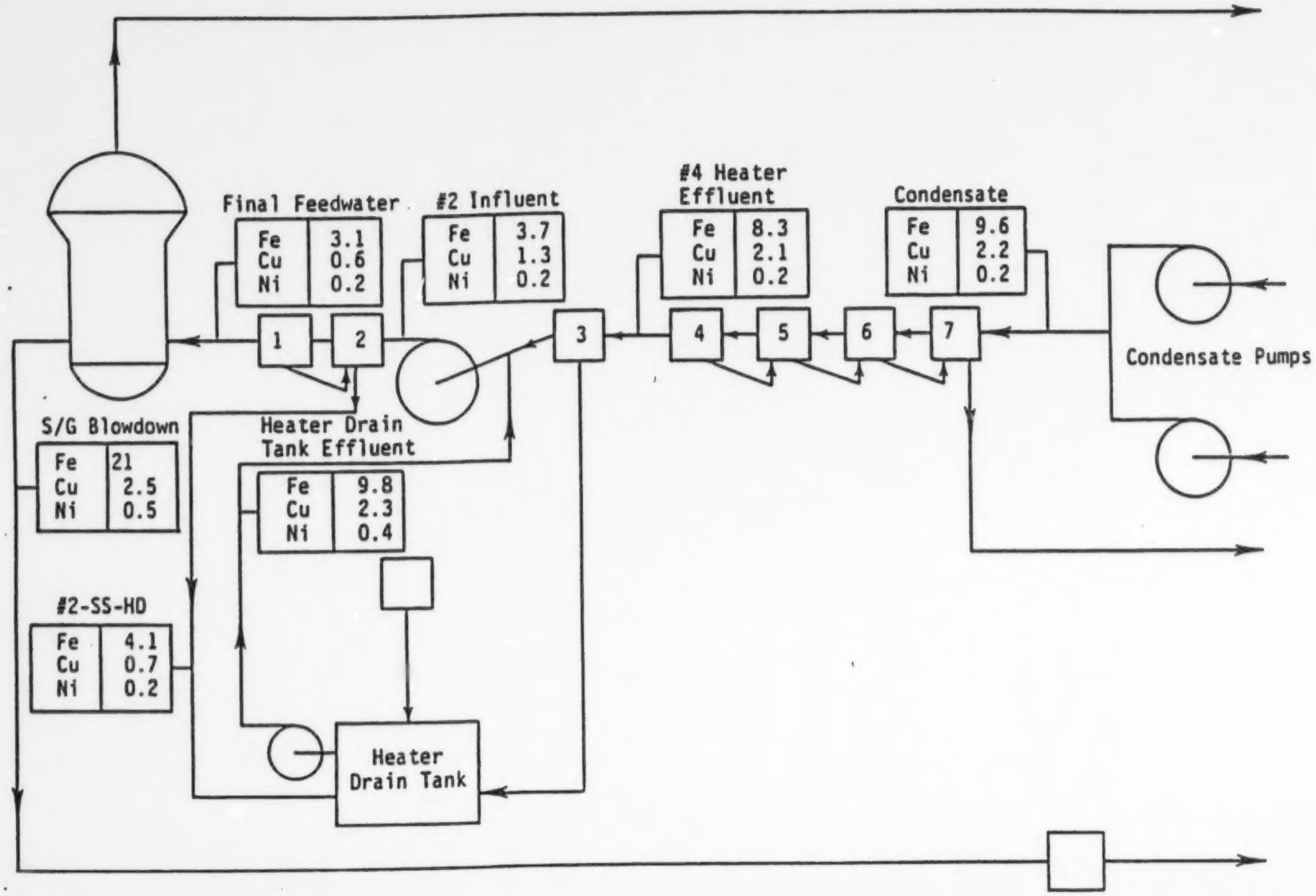

Final Feedwater
Fe 3.1
Cu 0.6
Ni 0.2
#2 Influent
Fe 3.7
Cu 1.3
Ni 0.2
#4 Heater Effluent
Fe 8.3
Cu 2.1
Ni 0.2
Condensate
Fe 9.6
Cu 2.2
Ni 0.2
1
2
3
4
5
6
7
Condensate Pumps
S/G Blowdown
Fe 21
Cu 2.5
Ni 0.5
Heater Drain Tank Effluent
Fe 9.8
Cu 2.3
Ni 0.4
#2-SS-HD
Fe 4.1
Cu 0.7
Ni 0.2
Heater Drain Tank

FIGURE A.3
POST-BORIC ACID TREATMENT AVERAGE CORROSION PRODUCT CONCENTRATIONS (ppb)
IN FEEDTRAIN A OF ANO-2

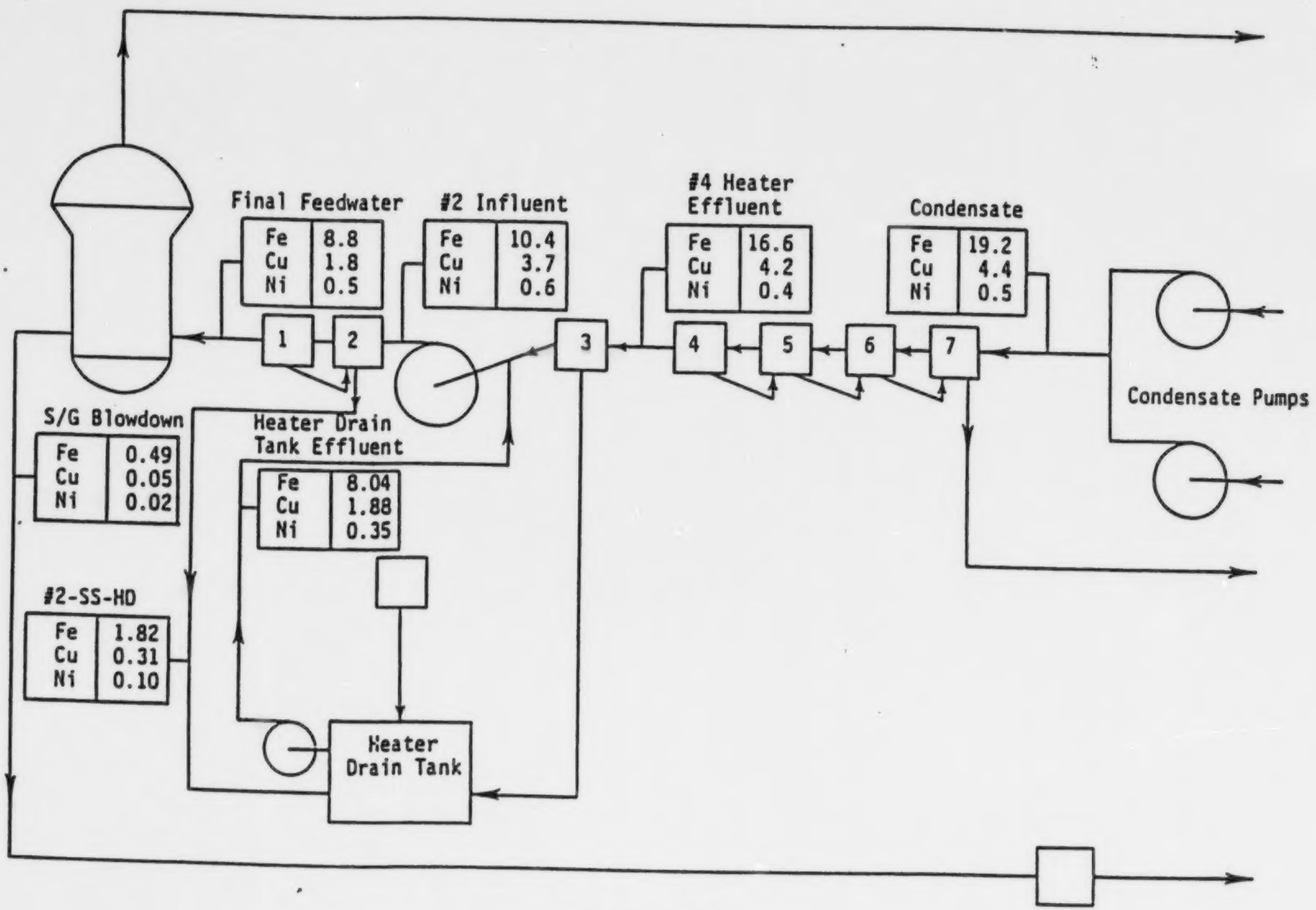

Final Feedwater
Fe 8.8
Cu 1.8
Ni 0.5
#2 Influent
Fe 10.4
Cu 3.7
Ni 0.6
#4 Heater Effluent
Fe 16.6
Cu 4.2
Ni 0.4
Condensate
Fe 19.2
Cu 4.4
Ni 0.5
1
2
3
4
5
6
7
Condensate Pumps
S/G Blowdown
Fe 0.49
Cu 0.05
Ni 0.02
Heater Drain Tank Effluent
Fe 8.04
Cu 1.88
Ni 0.35
#2-SS-HD
Fe 1.82
Cu 0.31
Ni 0.10
Heater Drain Tank

FIGURE A.4
POST-BORIC ACID TREATMENT AVERAGE CORROSION PRODUCT TRANSPORT RATES (g/h) IN FEEDTRAIN A OF ANO-2

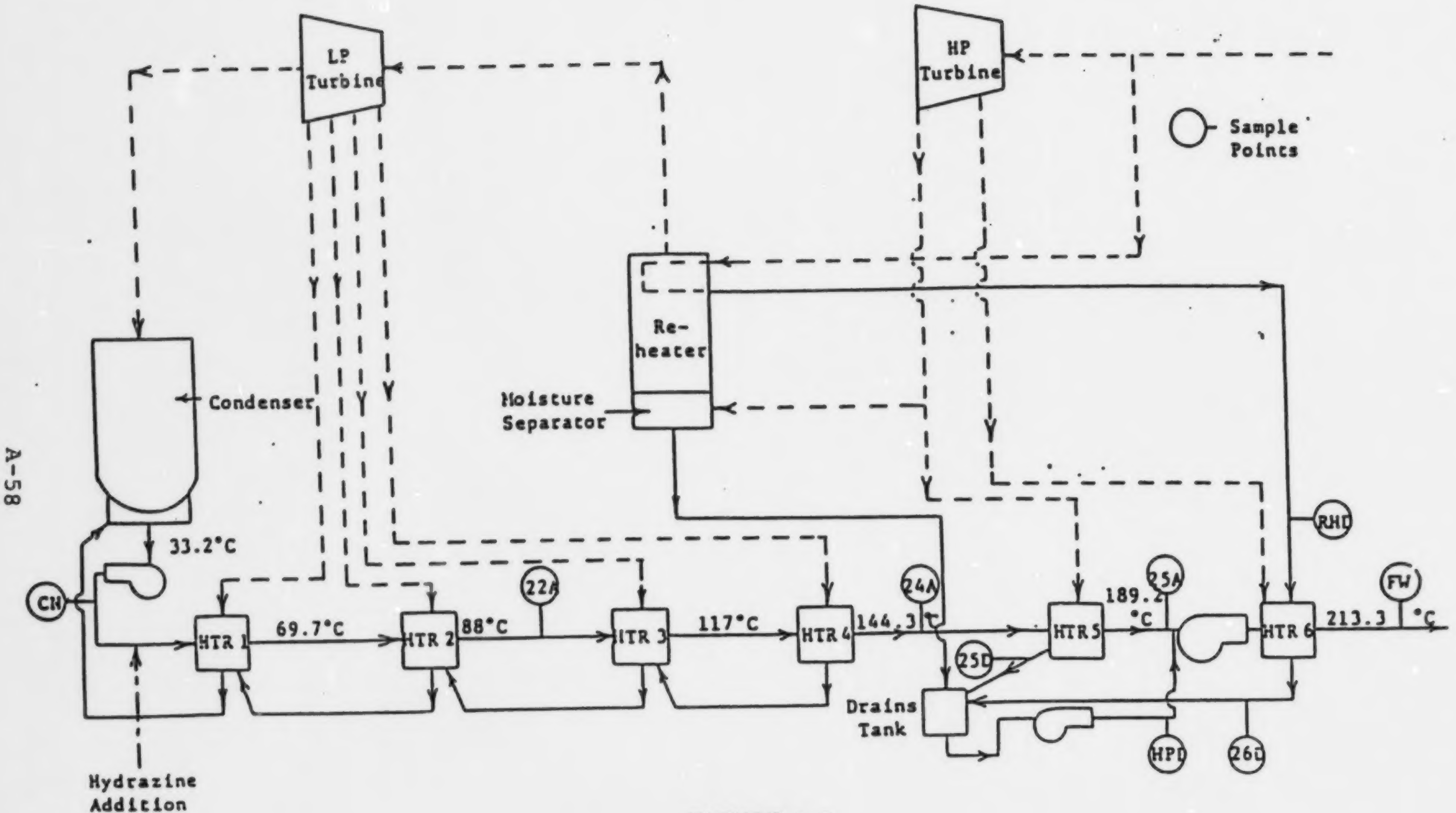

LP Turbine
HP Turbine
Sample Points
Re-heater
Moisture Separator
Condenser
33.2°C
CN
HTR 1
69.7°C
HTR 2
88°C
22A
HTR 3
117°C
HTR 4
144.3 °C
24A
25D
Drains Tank
HTR 5
189.2 °C
25A
HPD
26D
RHD
HTR 6
213.3 °C
FW
Hydrazine Addition

FIGURE A.5

SCHEMATIC DIAGRAM OF SECONDARY SYSTEM OF INDIAN POINT 2

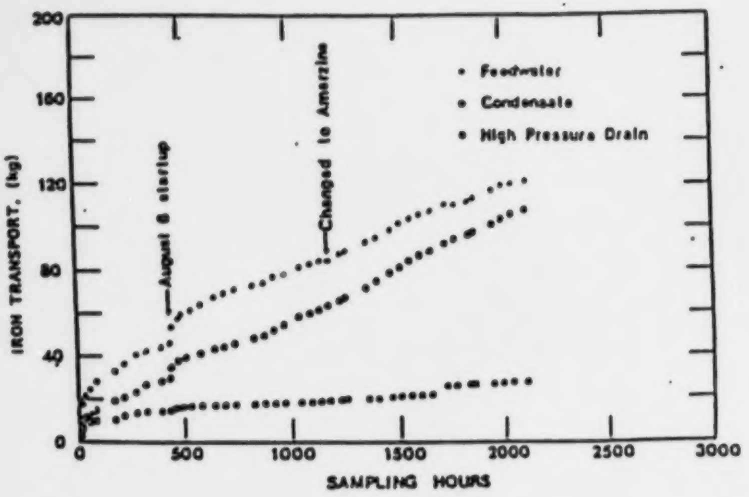


FIGURE A.6

IRON TRANSPORT IN CONDENSATE, FEEDWATER, AND HIGH PRESSURE DRAIN AT INDIAN POINT 2 FROM STARTUP (MAY 1977)

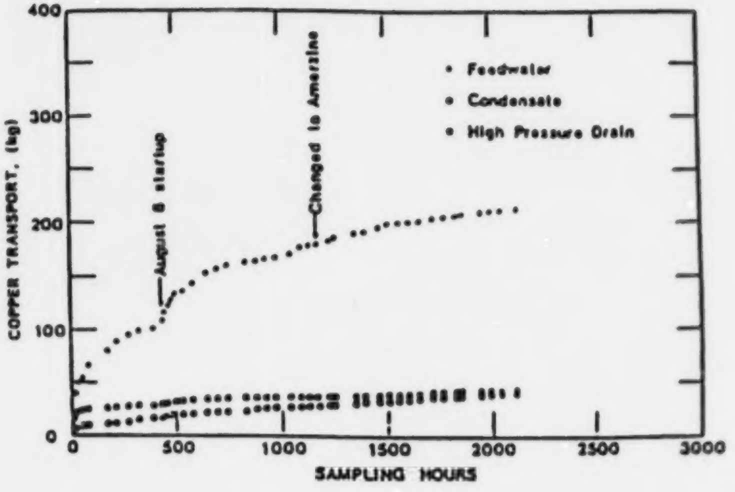


FIGURE A.7

COPPER TRANSPORT IN CONDENSATE, FEEDWATER, AND HIGH PRESSURE DRAIN AT INDIAN POINT 2 FROM STARTUP (MAY 1977)

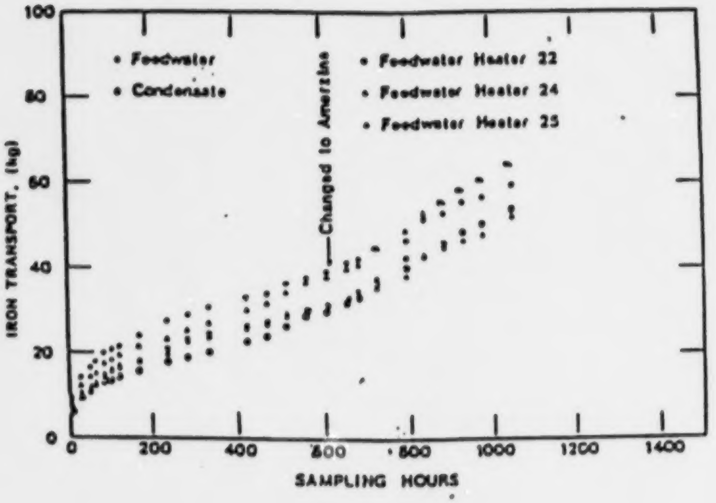


FIGURE A.8

IRON TRANSPORT IN CONDENSATE, FEEDWATER, HEATERS 22, 24 AND 25 FEEDWATER AT INDIAN POINT 2 FROM STARTUP (AUGUST 1977)

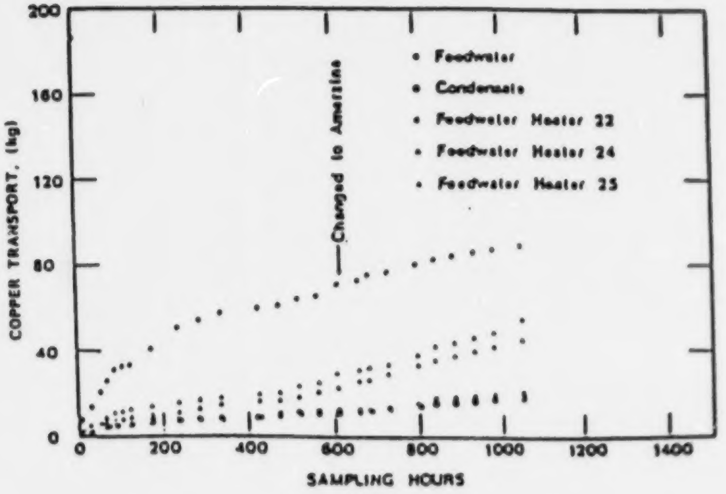


FIGURE A.9

COPPER TRANSPORT IN CONDENSATE, FEEDWATER, FEEDWATER HEATERS 22,24 AND 25 AT INDIAN POINT 2 FROM STARTUP (AUGUST 1977)

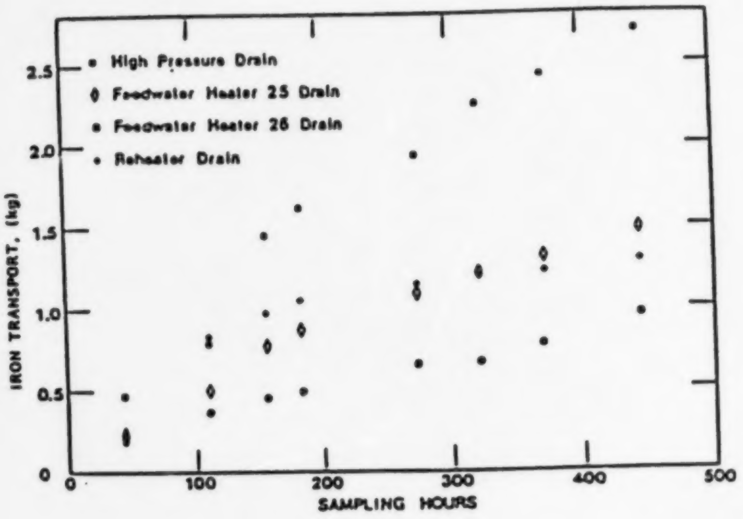


FIGURE A.10
IRON TRANSPORT IN DRAINS AT INDIAN POINT 2,
NOVEMBER 2 TO NOVEMBER 21, 1977

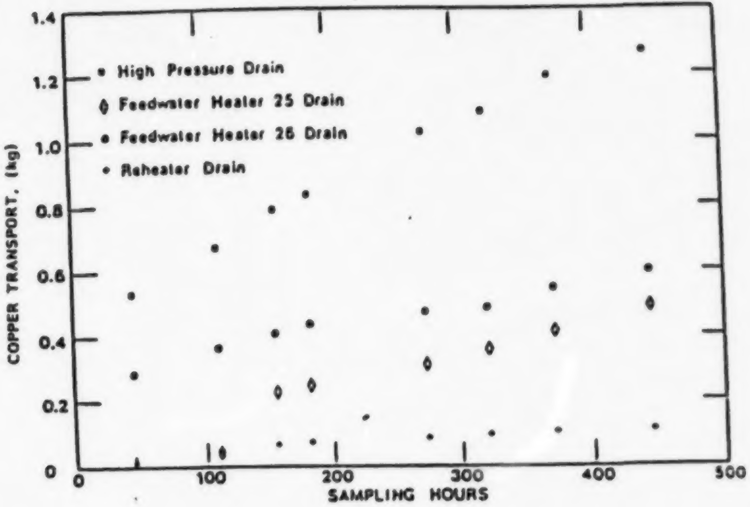


FIGURE A.11
COPPER TRANSPORT IN DRAINS AT INDIAN POINT 2,
NOVEMBER 2 TO NOVEMBER 21, 1977

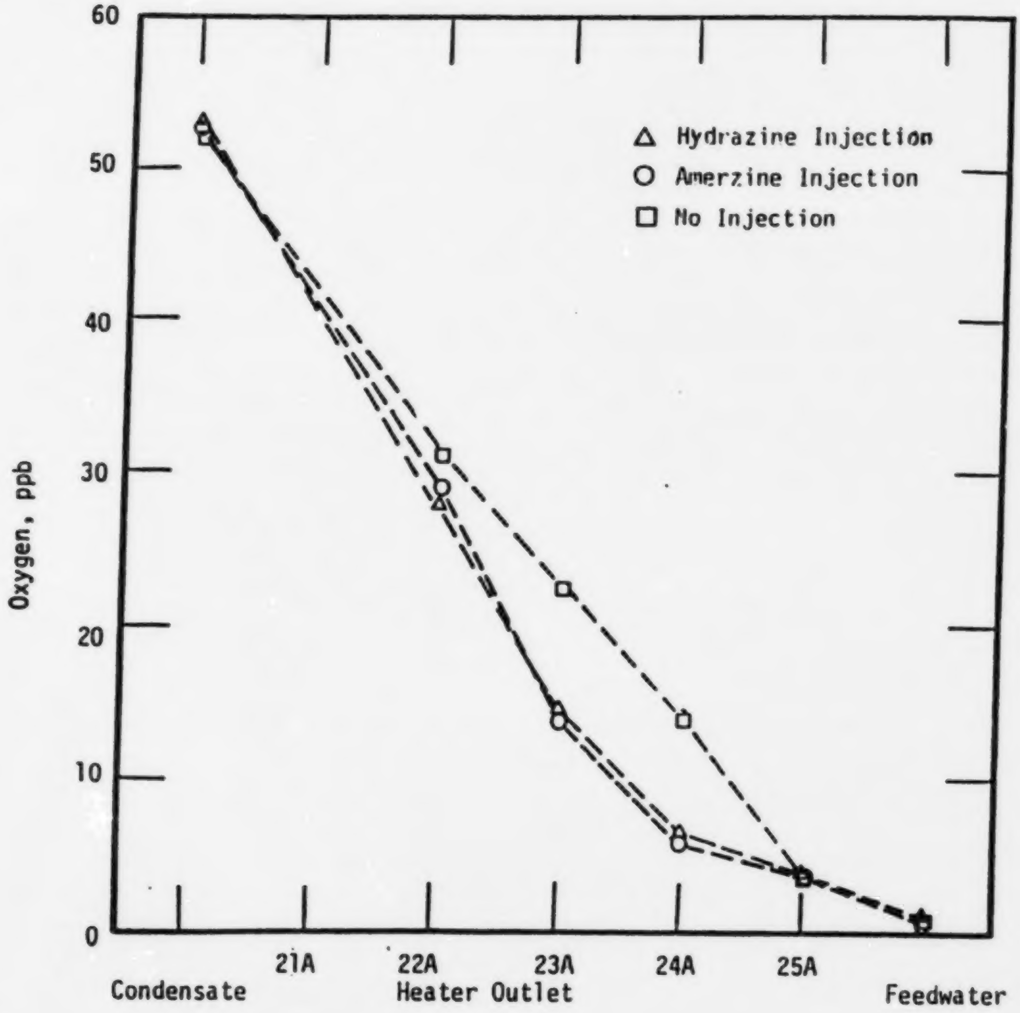
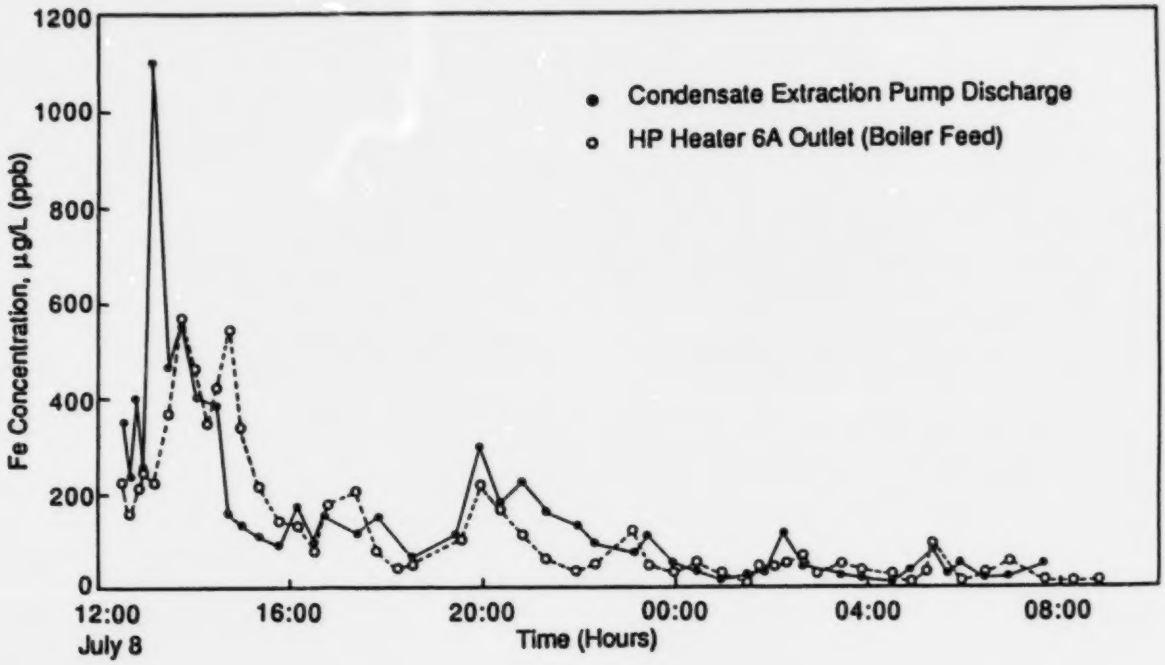


FIGURE A.12

AVERAGE OXYGEN CONCENTRATION IN THE FEEDTRAIN OF INDIAN POINT 2 IN SEPTEMBER, 1977 SAMPLING STUDY (REF. A-8)



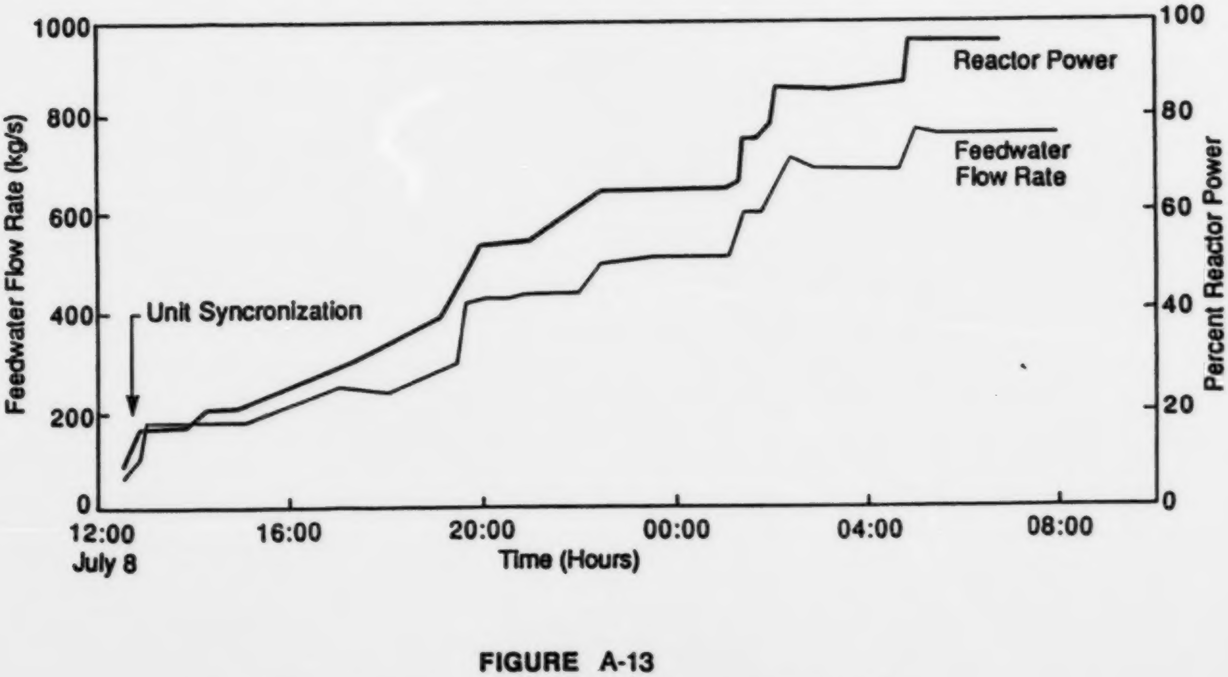


FIGURE A-13

IRON CONCENTRATION IN THE SECONDARY SYSTEM OF PICKERING-2 ON JULY 8, 1980 (Ref. A-12)

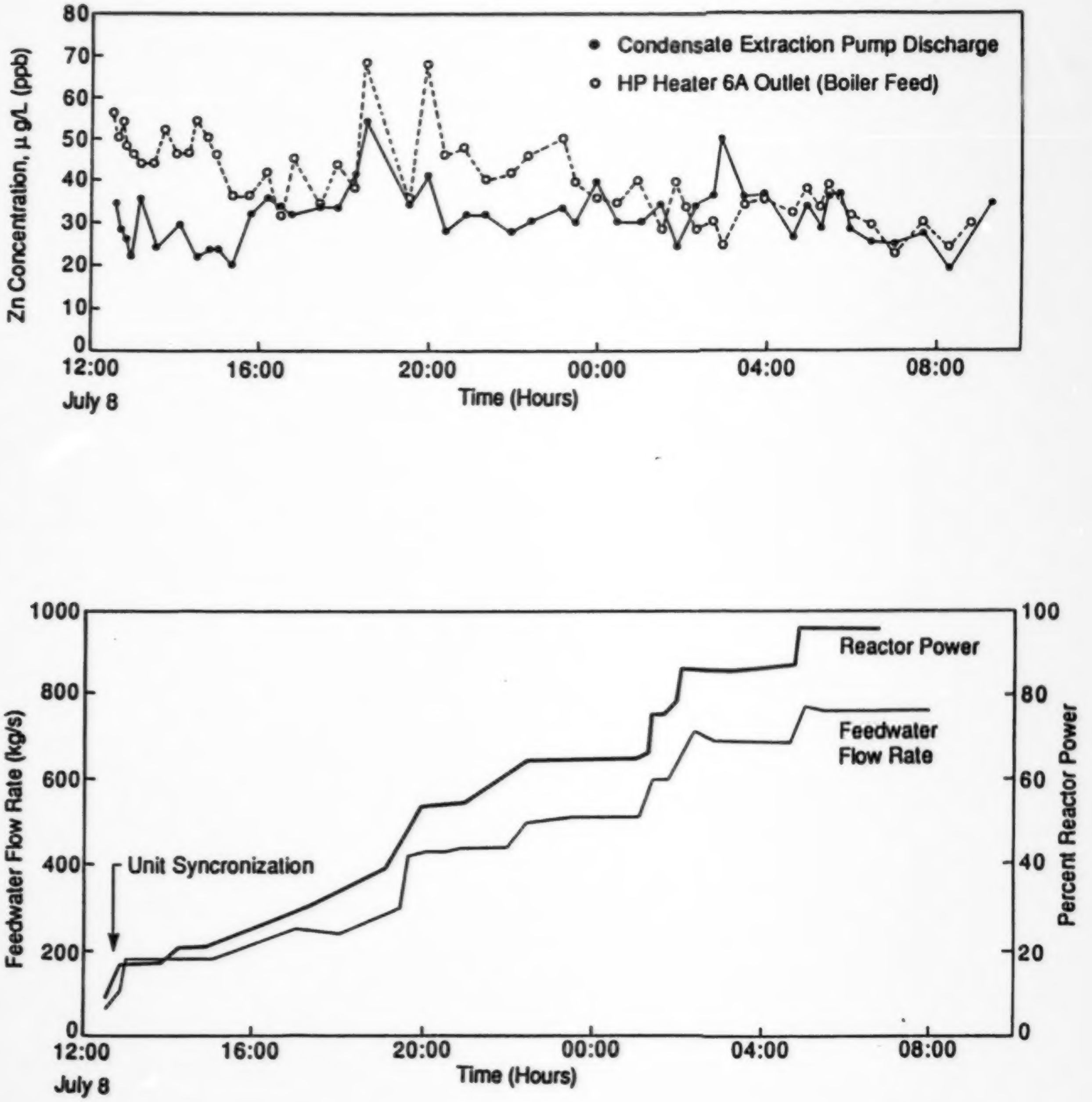


FIGURE A-14

ZINC CONCENTRATION IN THE SECONDARY SYSTEM
OF PICKERING-2 ON JULY 8, 1980 (Ref. A-12)

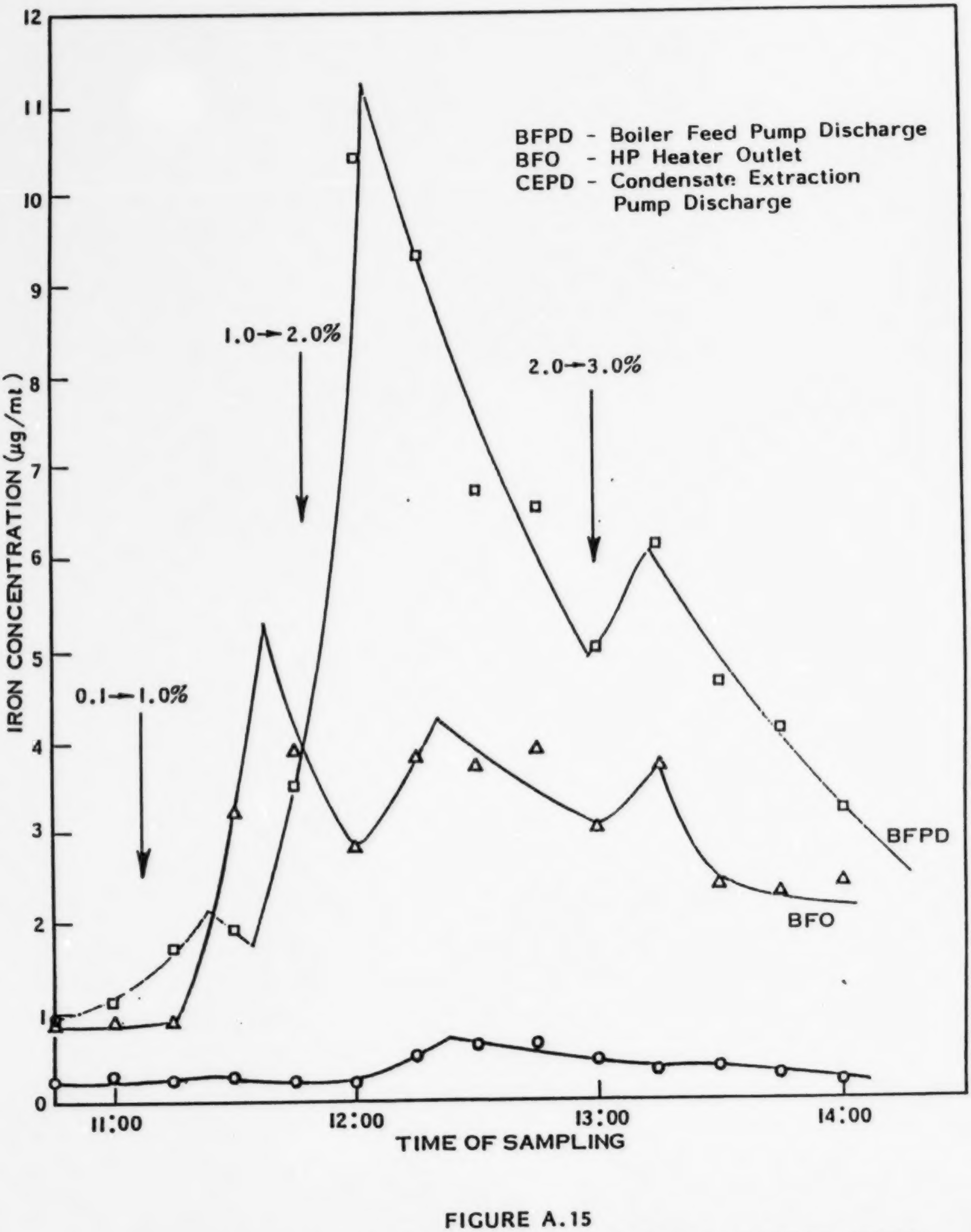


FIGURE A.15

IRON IN FEEDWATER OF BRUCE A UNIT 2 DURING REACTOR POWER INCREASE FROM 0.1 TO 3 PERCENT, AUG 28/76

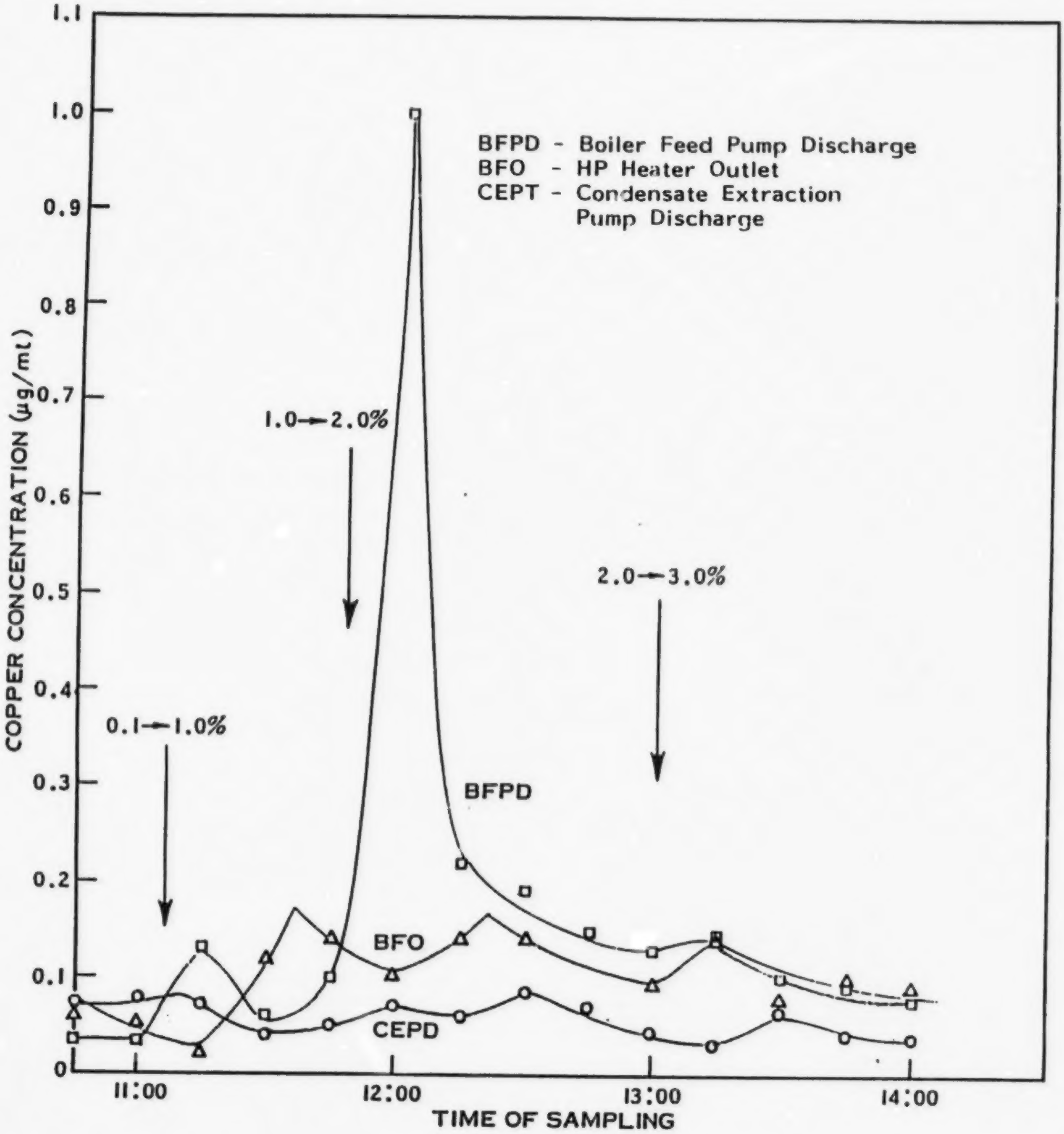
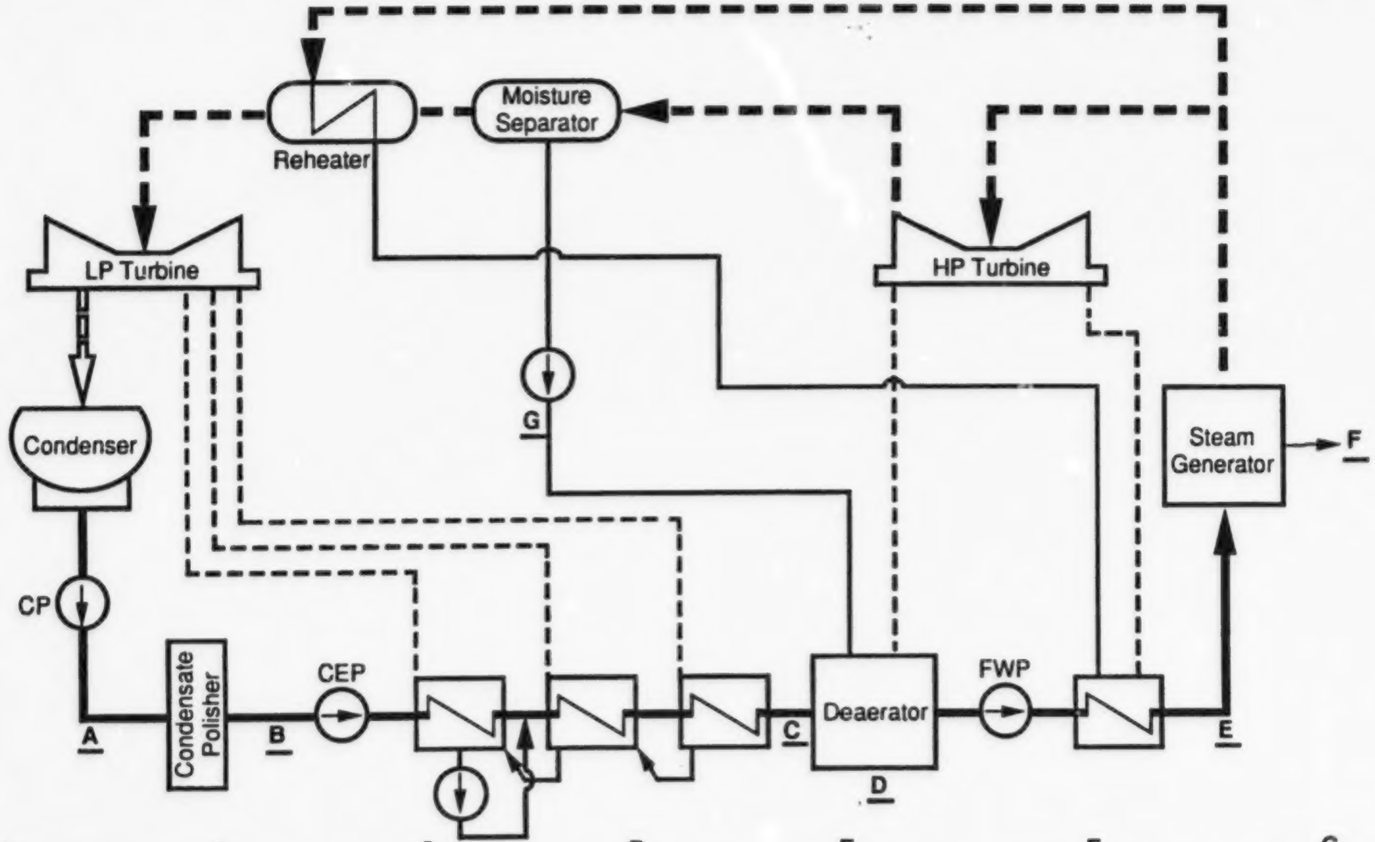


FIGURE A.16

COPPER IN FEEDWATER OF BRUCE A UNIT 2 DURING REACTOR POWER INCREASE FROM 0.1 TO 3 PERCENT, AUG 28/76


Reheater
Moisture Separator
LP Turbine
HP Turbine
Condenser
Steam Generator
F
G
CP
Condensate Polisher
CEP
FWP
Deaerator
A
B
C
D
E

A

μS	4.15
K-μS	0.11
DO$_2$	8 ppb
T-Fe	9 ppb
Na	0.02 ppb
Cl	0.12 ppb
T-Cu	1.1 ppb

B

μS	<0.1
T-Fe	3 ppb
Na	0.01 ppb
Cl	0.10 ppb
K-μS	0.06
T-Cu	<0.2 ppb

C

μS	3.95
T-Fe	5 ppb
T-Cu	<0.2 ppb
N$_2$H$_4$	0.19 ppm
K-μS	0.06

D

μS	4.0
DO$_2$	<2 ppb

E

μS	3.85
N$_2$H$_4$	0.22 ppm
T-Fe	13 ppb
T-Ni	0.6 ppb
K-μS	0.07

F

Blowoff (th^{-1})	5	20
pH	9.0	9.0
μS	2.8	2.8
K-μS	0.15	0.10
Na ppb	0.8	0.4
Cl ppb	5.6	2.0
Na/Cl	0.22	0.29

G

μS	2.05
K-μS	0.08
N$_2$H$_4$	0.72 ppm
T-Fe	28 ppb

Note: K-μS = Cation Conductivity

FIGURE A-17

WATER CHEMISTRY DATA OF THE SECONDARY SYSTEM IN A JAPANESE POWER PLANT (Ref. A-15)

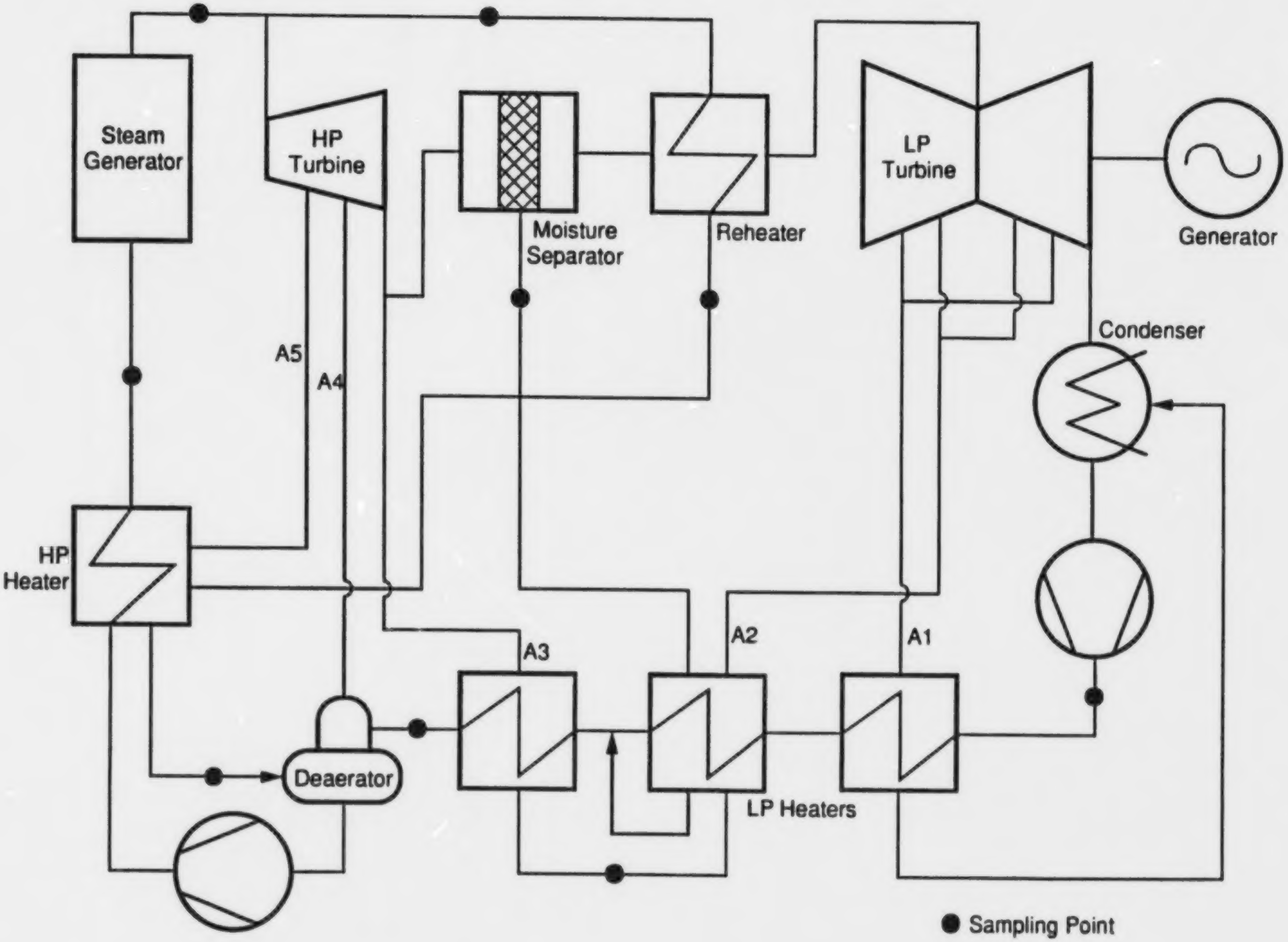
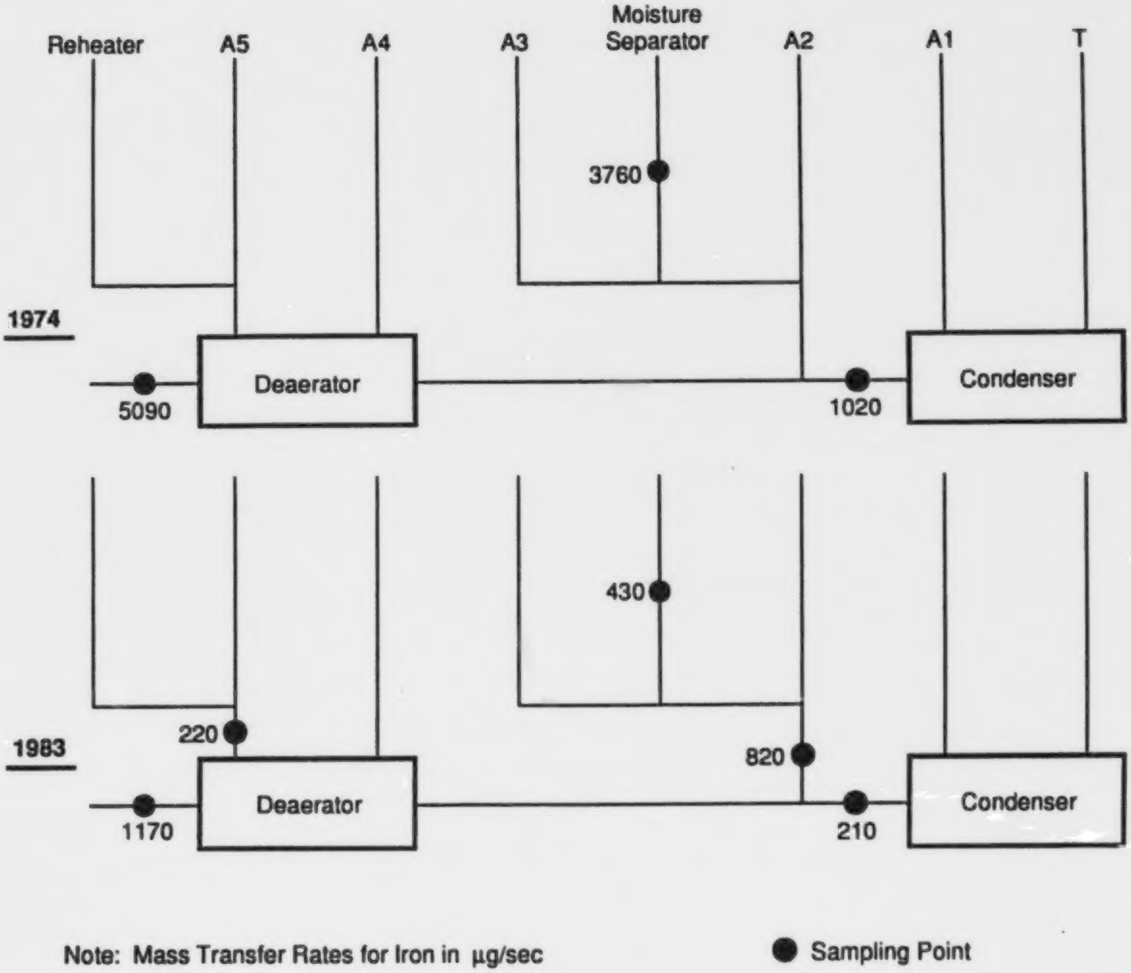

Steam Generator
HP Turbine
Moisture Separator
Reheater
LP Turbine
Generator
Condenser
HP Heater
A5
A4
A3
A2
A1
Deaerator
LP Heaters
● Sampling Point

FIGURE A-18

SCHEMATIC DIAGRAM OF THE SECONDARY SYSTEM OF BEZNAU-2 (Ref. A-16)



Reheater
A5
A4
A3
Moisture Separator
A2
A1
T
3760
1974
Deaerator
5090
1020
Condenser
430
220
1983
820
Deaerator
1170
210
Condenser
Note: Mass Transfer Rates for Iron in µg/sec
● Sampling Point

FIGURE A-19
COMPARISON OF IRON TRANSPORT RATES IN BEZNAU-2 SECONDARY SYSTEM DURING 2 SAMPLING PERIODS (Ref. A-16)